

HAWAII DEEP WATER CABLE PROGRAM  
BOTTOM ROUGHNESS SURVEY OF THE  
ALENUIHAHA CHANNEL

Prepared for:

HAWAIIAN DREDGING & CONSTRUCTION CO.

Prepared by:

MAKAI OCEAN ENGINEERING, INC.  
ED NODA & ASSOCIATES  
HAWAII INSTITUTE OF GEOPHYSICS

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## CHAPTER 1.

### INTRODUCTION.

This chapter provides background information for the Hawaii Deep Water Cable Program and describes the role that this study plays. The survey area and survey goals are discussed together with the difficulty of obtaining instrumentation to satisfy those goals.

#### 1.1 HAWAII DEEP WATER CABLE PROGRAM

The Hawaii Deep Water Cable Program is responsible for determining the feasibility of laying multiple power cables between the islands of Hawaii and Oahu in the Hawaiian Islands. One major obstacle identified early in the program is the Alenuihaha Channel, 1920m deep between Maui and Hawaii. Figure 1 shows the cable route between the islands and the area selected for this survey. The Alenuihaha channel has been identified as a major obstacle based on its extreme depth, very steep slopes and relatively recent geology. Studies done on both the Alenuihaha Channel and other comparable areas in the Hawaiian Islands led to the conclusion that this channel would be the major bottom roughness obstacle to the cable laying operation. Faults, lava flows, old shorelines, reefs and large vertical escarpments are typical underwater features on the steep slopes of the islands of Maui and Hawaii. (Reference 1,2)

#### 1.2 IMPACT OF ROUGHNESS ON CABLE LAYING

The Hawaii Deep Water Cable is a large complex structure with a wet weight of 27.1 kg/m and a diameter of 11.8 cm. This cable is laid on the bottom at a nominal tension (500 to 5000 kg) in order to prevent kinking during the laying process; if laid on a rough bottom the cable will be bent over obstacles and suspended between obstacles in free spans. The severity of these bends and the length of the spans is a function of the bottom roughness. The cable could be damaged during the laying process if the bend radius is less than 1.5 m, a value established by Pirelli Cable Corporation for this cable (Reference 3). Another failure mode is lead sheath fatigue caused by vortex-induced oscillations over time in the free span subjected to cross currents. Analysis by Pirelli shows that the acceptable free span length is a function of the bottom cable tension; as an example, a free span greater than 38 m in length at 3000 kg tension is unacceptable.

It is necessary to lay the cable on the bottom in the Alenuihaha Channel without unacceptable spans and without unacceptable bend radii. The size of the cable spans and the severity of a cable bend is a function of the bottom roughness. In order to determine the difficulty and the cost of laying the cable, the bottom roughness must be determined.



### 1.3 SURVEY GOALS

The following goals have been established for the preliminary survey of the Alenuihaha Channel:

- 1.3.1 Perform a preliminary survey of the bottom of the Alenuihaha Channel characterizing the bottom roughness in terms meaningful to the HDWC cable laying process and evaluation.
- 1.3.2 Perform a preliminary identification of the bottom roughness "problem" in terms of free spans,, cable bending radii and escarpments leading toward the eventual:
  - A. Location of an acceptable cable path across the Alenuihaha Channel
  - B. Identification of the degree of placement accuracy required for the successful deployment of a cable across the Alenuihaha Channel.
  - C. Identification of the optimal bottom cable tension and tolerance for laying a cable in the survey area.
- 1.3.3 Identify the needs for subsequent surveys beyond this preliminary survey.
- 1.3.4 Measure the bottom roughness along selected tracks by measuring detailed bathymetry with a 15 cm vertical resolution and a 1.3 m horizontal resolution. The horizontal distance measurement should not be distorted by more than  $\pm 10\%$  over any 100 m track segment. The absolute geographic location of an individual track is less important and should be within 5% of water depth (100 m).

### 1.4 SURVEY AREAS

Figure 2 illustrates the primary survey areas within the Alenuihaha Channel. Figure 3 illustrates a typical profile plotted to true scale.

Area A is the primary survey area and consists of the Kohala Slope, the steepest slope (27 degrees max.) along the entire cable route; it drops from 900 m to 1900 m. The second most important area of interest is Area B on the Haleakala slope. The third order of priority are the areas C1, C2 and C3 which are above and below areas A and B.

The SeaMARC sidescan system, operated by the Hawaii Institute of Geophysics, has been flown in the area prior to this survey.

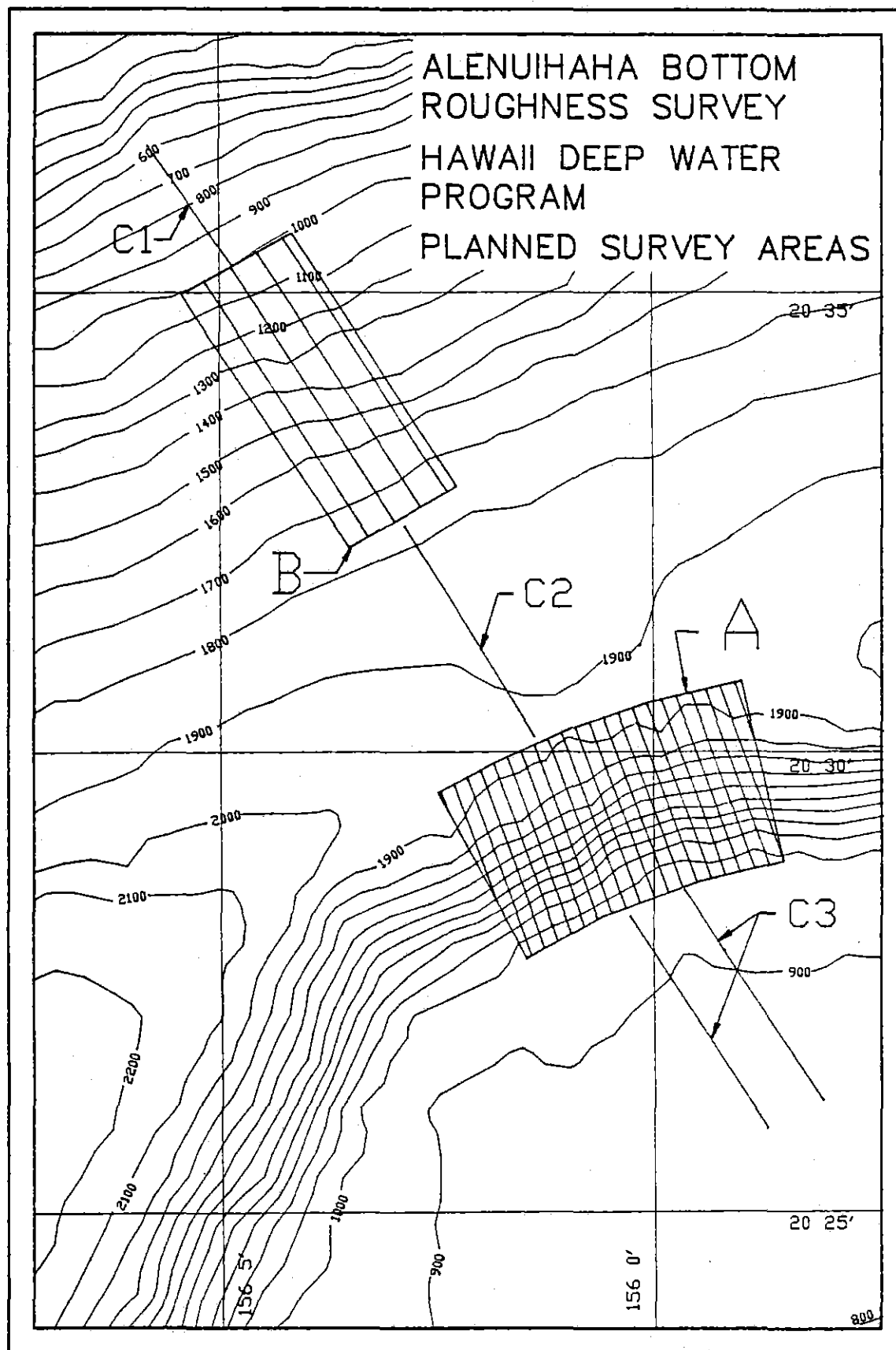


FIGURE 2: Specific survey sites in the Alenuihaha  
Channel: Cruise #1

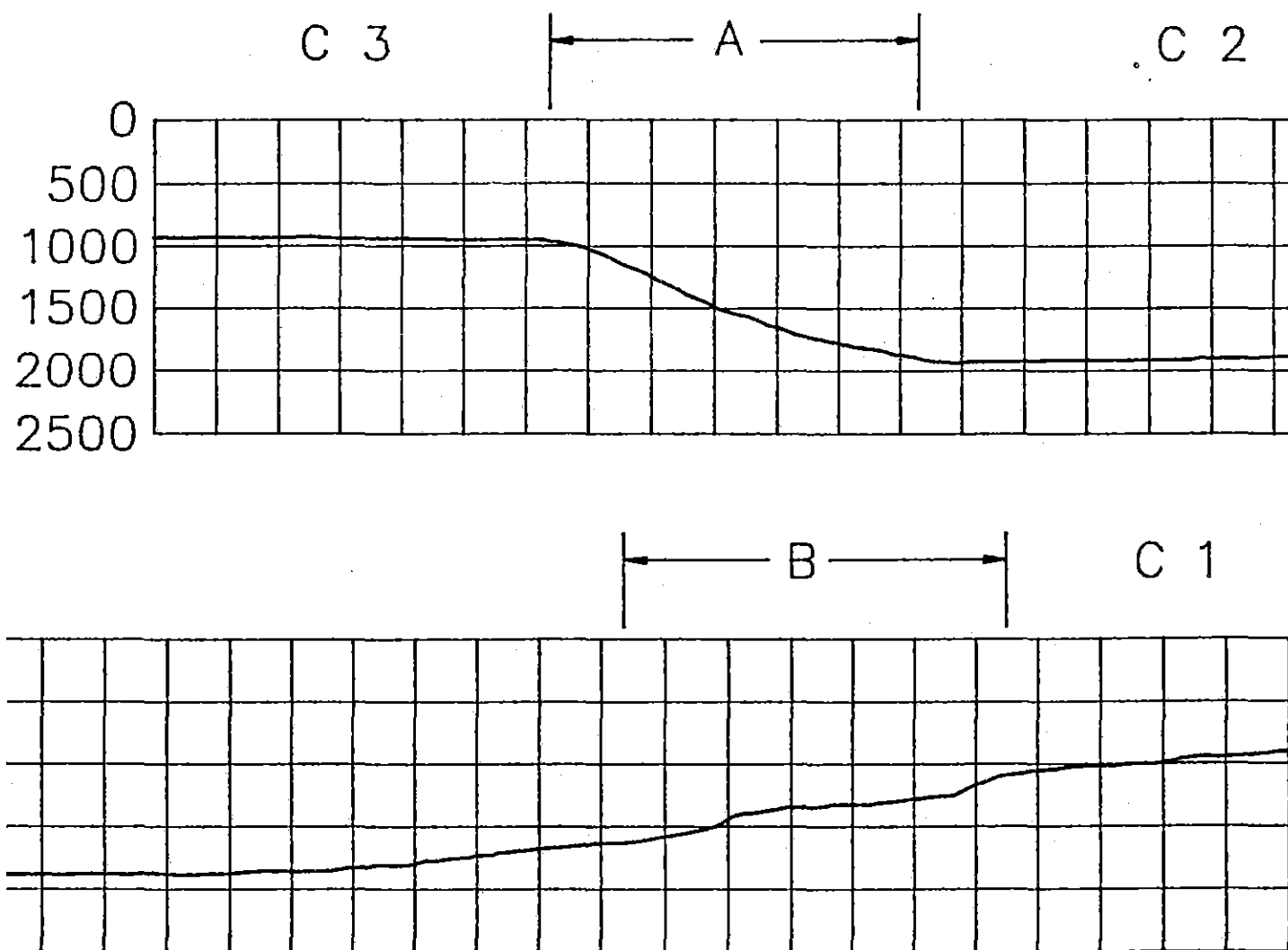


Figure 3: Profile of survey area, Alenuihaha Channel  
Scale is 1 to 1. Units in meters.

Some of the corrected data is shown in Figure 4. Note that the Kohala Slope clearly shows as a dark band, apparent lava flows can be seen in area C3 and a variety of irregular features are seen on the Maui slope. The bottom of the channel appears relatively clear.

## 1.5 THE INSTRUMENTATION PROBLEM

A typical cable span laid at 5000 kg would be 25 m long with a sag of 0.5 m in the middle. The bottom roughness survey must therefore identify bottom topography which would cause such unsupported free spans. The criteria that have been established for this survey call for a vertical resolution of 0.15 m (6 in) and a horizontal resolution of 1.3 m (4 ft). Note that this is resolution, not accuracy. The resolution, the position relative to adjacent points, needs to be small in order to identify areas which would cause cable spans.

Conventional surface bathymetric acoustic measurements do not give the type of resolution required for this program. These techniques sample and average areas which are many times larger than the cable spans of interest and therefore such data is unacceptable. Bottom 3-D photography offers a means of obtaining fine resolution bathymetry of the bottom but the sample areas are typically too small at 5 to 10 m on the side of the photograph. A third sampling method considered was side scan sonar: this technique provides good qualitative data to either side of a towed fish; the resolution and coverage area is a function of the acoustic frequency. SeaMARC is an example (Figure 4) of a very wide swath, low frequency side scan system. Side scan systems will not provide quantitative data necessary for evaluating the potential and size of cable spans.

A variety of deepwater ROVs, submersibles and towed systems were evaluated in terms of ability, cost and availability. Any potential sampling system needed to be available in the October/November 1985 time frame in order to avoid the severe winter seas. The most suitable system for the survey was Scripps' Deep Tow package but this was not available in the fall.

The final approach selected for this program was to build a small roughness sampling package that is towed close to the bottom and acoustically measures the bottom roughness. This instrumentation, coupled with more surveys by the University of Hawaii SeaMARC system was selected as the best means of economically and quickly conducting a preliminary bottom survey.

## 1.6 SCHEDULE

The entire survey was kept on a relatively tight schedule. The instrumentation design and survey planning were conducted in early September. All equipment was fabricated and assembled in the



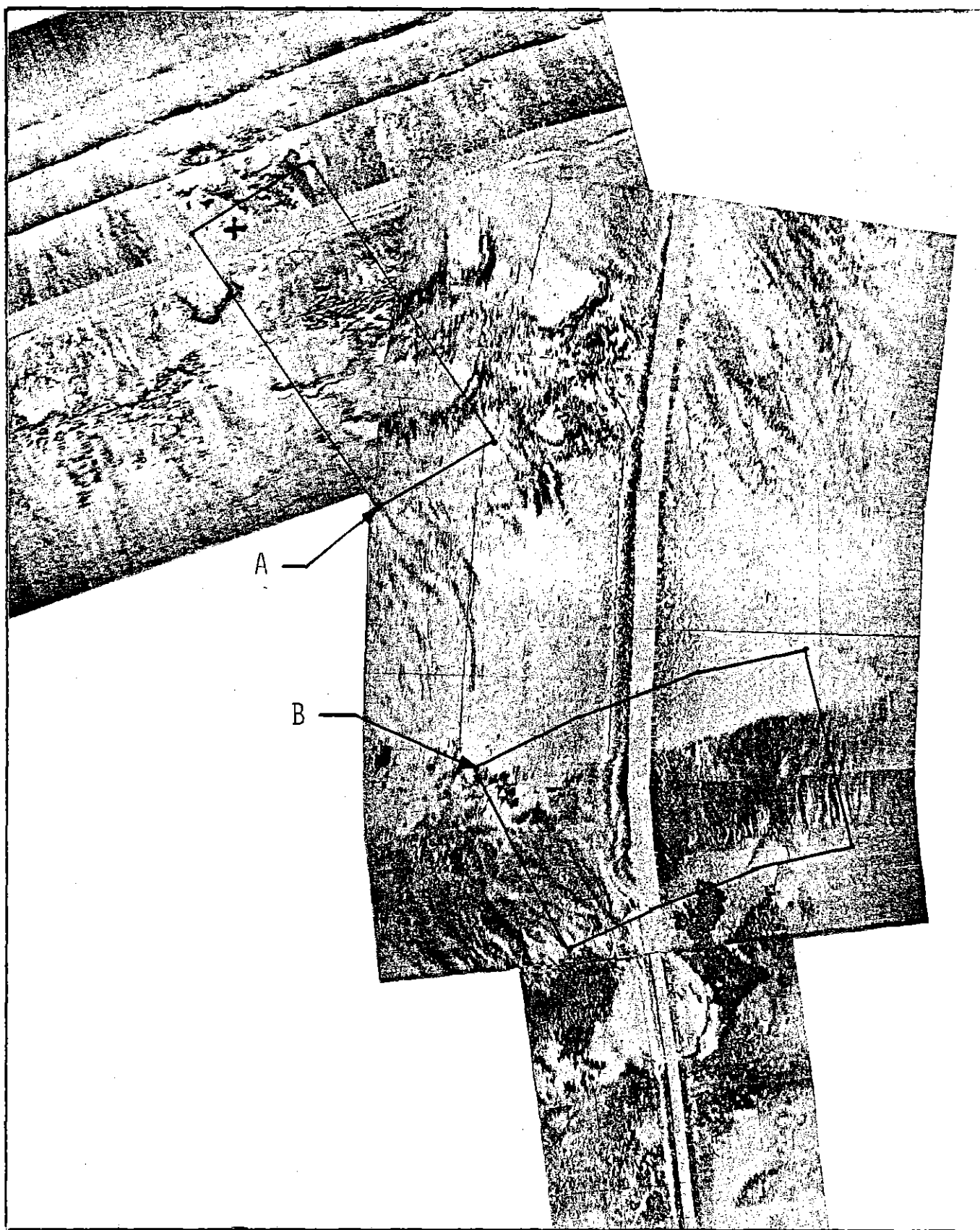


Figure 4 Sea Marc data from previous surveys in the Alenuihaha Channel. Boxed areas are survey sites A and B.

following month and on October 24 a shakedown cruise was conducted. The following five days included SeaMARC runs along the cable route, in the Alenuihaha Channel and at the Cross sea mount (a program independent of the HDWC survey). On October 29 through November 6 the detailed bottom roughness survey was conducted in the channel, two months after initiating the design.

## 1.7 PARTICIPANTS

The Hawaii Deep Water Cable Program is funded by the U.S. Department of Energy, and the Hawaiian Electric Company is the prime contractor. Ralph M. Parsons Co. manages the HDWC program for Hawaiian Electric. For the preliminary deepwater survey, the following organizations participated directly:

Hawaiian Dredging & Construction acted as the major subcontractor and provided overall management for the deepwater survey.

Makai Ocean Engineering provided the principal investigator and was responsible for data analysis and survey planning.

Edward K. Noda and Associates was responsible for the instrumentation development and operation during the cruise.

The University of Hawaii and the Hawaii Institute of Geophysics provided the research vessel, MOANA WAVE, and assisted in the design and fabrication of the Bottom Roughness Sampler.

Sci-Tech, a Wimpole Company, provided the acoustic and surface navigation equipment and operators.

## CHAPTER 2.

### EQUIPMENT AND METHODOLOGY

#### 2.1 EQUIPMENT

##### 2.1.1 Bottom Roughness Sampler

The overall survey system is illustrated in Figure 5. The Bottom Roughness Sampler (BRS) was towed at 20 to 30 m off the bottom along a desired survey track. The sampler measured and recorded the BRS depth,  $Z$ , and the height above the bottom,  $H$ . The sum of these two measurements provided an accurate recording of the depth of a 1.5 m diameter sample area directly below the BRS. The BRS contained a pressure transducer which measured  $Z$  to a 15 cm resolution and a 500 kHz echo sounder which measured  $H$  to a 2 cm resolution. A data logger on the BRS recorded the  $Z$ , and  $H$  at 1 second intervals. Also on the BRS was a 12 kHz pinger which provided a direct and bottom reflected signal to the surface ship for controlling the BRS altitude above the bottom. For positioning of the BRS, a transponder was provided on the BRS frame as part of a long base acoustic navigational system.

The BRS frame was a fabricated box beam structure designed for maximum pitch and roll stability. Its total wet weight was 3100 lbs which helped to minimize the towing distance aft of the MOANA WAVE. The lead weights were located low in the BRS frame in order to keep the angular tilt at a minimum. The BRS pitched forward less than 2 degrees at 0.75 m/s (1.5 kts) and its pitching natural frequency was much less than 5 seconds. The frame design is provided in the Appendix.

Since the bottom roughness measurement instrumentation system recorded all data at depth using a data logger, information on the altitude of the BRS off the bottom was required in real-time during a data run in order for the winch operator to maintain altitude control. A 12 kHz pinger was used for this purpose, which was also housed within the BRS. By monitoring the direct return as well as the reflected return from the bottom using onboard recorders, the real-time altitude of the BRS was continually monitored. Two techniques for transferring this altitude information to the winch operator were employed. The standard method was to provide verbal instructions via walkie-talkie. An additional technique employed was to utilize a closed-circuit TV system, where a video camera was mounted over the recorder and the image transferred to a monitor located on the open deck at the winch operator's station. This latter technique proved to be very useful and allowed the winch operator to control the vehicle attitude independently to maintain a distance of 20-40 meters off the bottom.

# ALENUIHAHA BOTTOM ROUGHNESS SURVEY HAWAII DEEP WATER PROGRAM

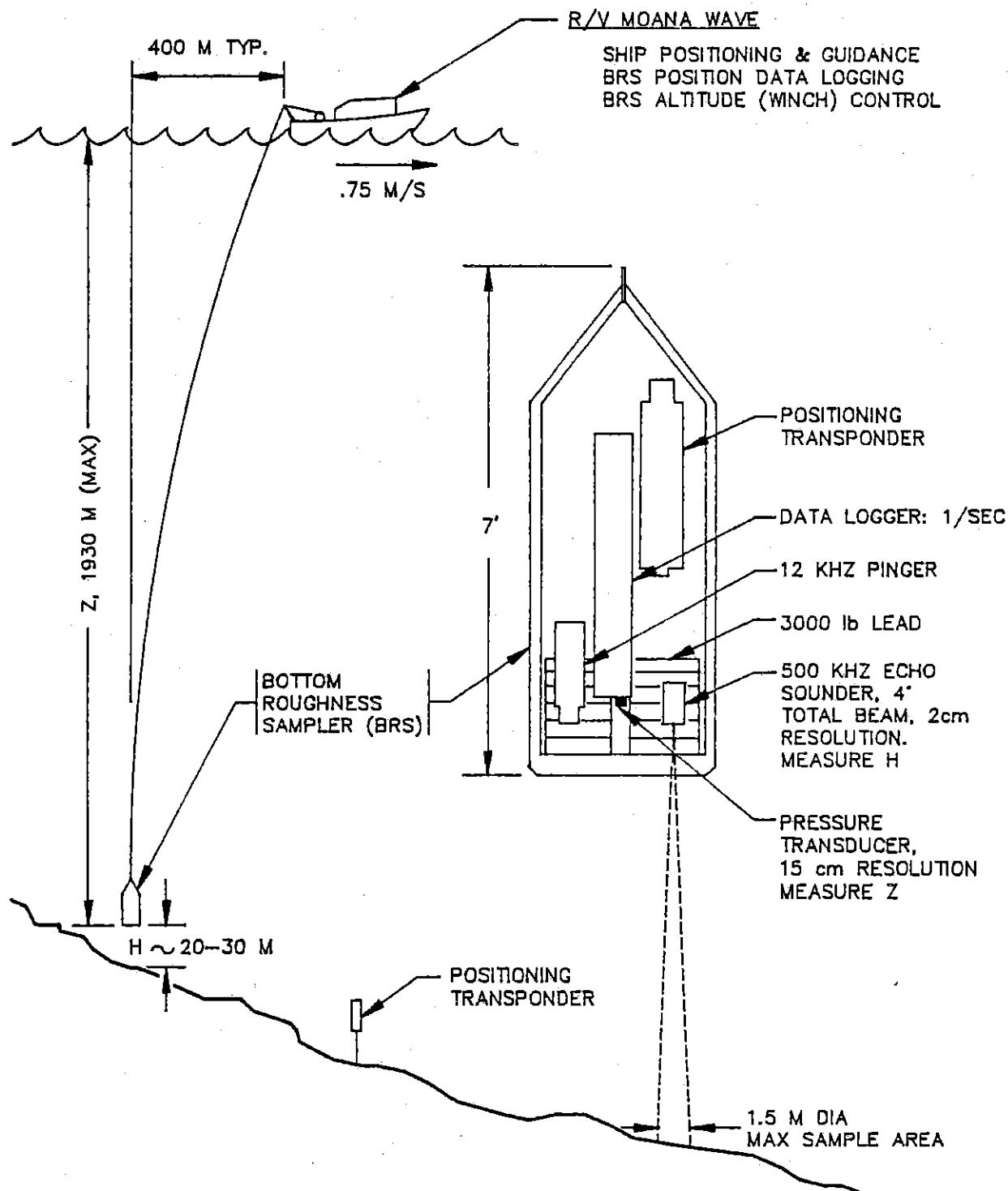


FIGURE 5

The Ulvertech Model 205 Echo Sounder was selected as the bottom roughness profiler, which operates at about 500 kHz with a 4 degree beam angle at 3dB points. The Model 205 Echo Sounder has a nominal range of 100 m with a resolution and accuracy of  $\pm 2$  cm (0.8 inch). The echo sounder is nominally rated for a water depth of 1,500 m, and since our depth requirements were greater, a new pressure housing was manufactured by HIG, University of Hawaii.

The selected pressure sensor was a Paroscientific, Inc. digiquartz pressure sensor Model 43K-027 with a pressure range of 0-3,000 (20.68 MPa) psia. The manufacturer's repeatability and hysteresis specifications are  $\pm 0.01\%$  of full scale (0.3 psi or about 0.67 ft of water). While the repeatability and hysteresis when converted to actual water depth exceeds the required specifications for the survey, conversations with Paroscientific indicated that the specifications were very conservative and that actual performance would be significantly better than the specifications. Pressure resolution tests confirmed this increase in performance.

The data recording system selected was the Sea Data Corporation Model 650B-7 Data Logger. Since the provided pressure housing was not rated for this depth, a special housing was machined by HIG, University of Hawaii. This housing also contained the Paroscientific pressure sensor as well as a battery pack for the echo sounder.

#### 2.1.2 Vessel and Winch

The vessel used for the Bottom Roughness Survey was the University of Hawaii research vessel R/V MOANA WAVE. The MOANA WAVE is 65 m (312 ft) long and is powered by twin variable pitch propellers and a bow thruster. Due to the low speed requirements of the survey as well as the fact that the track lines would be perpendicular to the expected wind and wave directions, maneuverability capability offered by the variable pitch propellers was essential. The R/V Moana Wave has a Markey winch with 14,000 m of 9/16", 3x19 torque-balanced wire rope. The winch has a maximum speed of about 2 meters/sec.

#### 2.1.3 SeaMARC

The SeaMARC II mapping system is a one-of-a-kind side scan sonar system manufactured by International Submarine Technology, Ltd., with the capability of developing quantitative bathymetry data simultaneous with the acquisition of standard side scan imagery. While the SeaMARC II system is unique and provides very useful global data, its resolution is relatively coarse and not sufficient to provide the high resolution bottom roughness data required.

#### 2.1.4 Navigation

Surface navigation was provided by a Del Norte Technology, Inc. Trisponder system with an overall accuracy of 3 meters. The Trisponder is a microwave line-of-sight range-range positioning system which utilizes shore stations for positioning. Its total range is 50 miles, more than adequate for this survey. To provide redundancy, two complete Trisponder navigation systems and a Mini-Ranger III system built by Motorola, Inc. were utilized.

The two shore stations were located on Maui at the following locations:

Location	X	Y	Z
Kahikinui	190789.6 m	31274.0m	439 m
Muolea	219737.0 m	39543.7 m	98 m

The navigational grid used during this survey was the U.S. Coast and Geodetic Survey Transverse Mercator, Zone II, Maui, in meters.

The surface navigation was linked through a Hewlett Packard 9826 computer to display on a color monitor the MOANA WAVE position, selected track, vessel heading and speed, and the distance the vessel is either to the right or left of the desired track. A repeater monitor was provided on the bridge and proved to be an extremely valuable tool to the ship's crew in keeping the MOANA WAVE along a desired course.

#### 2.1.5 Acoustic Bottom Positioning Equipment

A long baseline acoustic navigation grid with a transponder bottom grid was deployed on the Kohala slope in order to provide accurate bottom positioning for the BRS. Unfortunately, this equipment never operated properly and bottom BRS positions were never directly measured. Positioning of the BRS was later determined by calculations based on the BRS depth, vessel speed and wire rope lengths.

The intent for the acoustic positioning system was to lay a six-transponder grid on the bottom with a master transponder on the BRS. By accurately positioning two of the bottom transponders through a lengthy range-range measurement calibration from the surface vessel and coupling these ranges with accurate surface navigation, the entire bottom grid could be accurately referenced to the surface range-range navigation system and grid.

Although the transponders were deployed, the master transponder on the BRS failed to range to the bottom transponders. Throughout the cruise attempts were made by the manufacturer's representatives to make the system operational but without success; a wide variety of BRS/transponder configurations were tried. More information on this effort is provided in the cruise log in the Appendix.

Fortunately, for this particular cruise the exact position of the BRS was not critical to the bottom roughness assessment. It was still possible to obtain an accurate definition of the bottom roughness by using the ship positioning and speed. Ship position was digitally recorded every 10 seconds during each track. By knowing the ship position, BRS depth and occasional cable lengths, the distance of the BRS behind the surface ship could be approximated such that adjacent tracks could be reasonably well positioned relative to each other.

While preparing for the survey cruise, detailed preparations were made for the proper placement and deployment of the transponder grid. This grid was both deployed and successfully retrieved during the cruise. Most of the bottom transponders were able to communicate with each other indicating a clear acoustical path. Proper pendant length and transponder placement is critical to the intercommunication between transponders. Included in the Appendix are detailed calculations by Noda & Associates relative to the refraction of the acoustic waves in deep water. This information is provided for subsequent cruises.

#### 2.1.6 Computers

The data analysis was initiated as soon as the BRS data was available. Four WANG PCs were used to initially scan the data and to plot profiles of the detailed depth, pressure signal and the echo sounder signal. This data was plotted with a Houston Instruments 24x36 inch plotter.

#### 2.1.7 Oceanographic Instrumentation

In addition to the primary detailed bathymetry, several standard oceanographic instruments were continually operated throughout the cruise. Those most important to the HDWC program included the bottom bathymetry continually plotted from a 3.5 kHz signal. In addition, a Doppler current profiler was continually run throughout the cruise. Every five minutes it recorded water velocity relative to the ship for 62 locations at 8 meter spacing below the vessel. This data is currently stored by the Oceanography Department at the University of Hawaii and is not being processed as part of this survey. For processing, the data needs to be corrected for the vessel speed and direction.

### 2.1.8 Equipment Redundancy

Because of the very high cost of operating this cruise at sea, a full redundancy on all components in the program was provided. Even if the entire BRS were lost, the survey could have continued with the redundant equipment onboard. No equipment was lost during the cruise but backup echo sounders and Trisponder stations proved to be critical to the continuing success of the survey.

## 2.2 OPERATIONS

### 2.2.1 SeaMARC Survey

The tow path followed by SeaMARC is shown in Figure 6. Tows parallel, perpendicular and diagonal to the slope were all run to obtain the most information through the variety of shadows provided by a side scan system.

The uncorrected side scan data was provided in real time and this data proved useful in selecting likely paths for the fine resolution BRS system. The final corrected data was provided after several months of processing at the University of Hawaii and is included later in this report. This data is valuable in the planning of the second survey cruise.

### 2.2.2 Bottom Roughness Sampler Operation

The specific tracks for the BRS operation were only generally selected prior to the cruise. Approximately 65% of the survey time was allocated to Area A, 20% to Area B and 15% to Areas C. The actual route selection was based on the SeaMARC data collected earlier in the cruise and the profiles generated by the most recent BRS operation.

The BRS was operated 24 hours a day and cycled typically every 10 or 12 hours. During this time, multiple tracks were followed, usually 4 km per track and 3 to 5 tracks per cycle of the BRS. During this cycle, over 40,000 data points would be collected with 20,000 to 30,000 points actually on the bottom.

For a particular track, the navigator displayed the desired track and the ship's current position on the bridge color monitor. The ship would be aligned with the track and the BRS lowered such that it was 20 to 30 m off the bottom before the ship actually reached the start of the track. The tow would proceed along a straight path, guided by the excellent computer feedback on the monitor, at a speed of approximately 0.75 m/s (1.5 Kts).



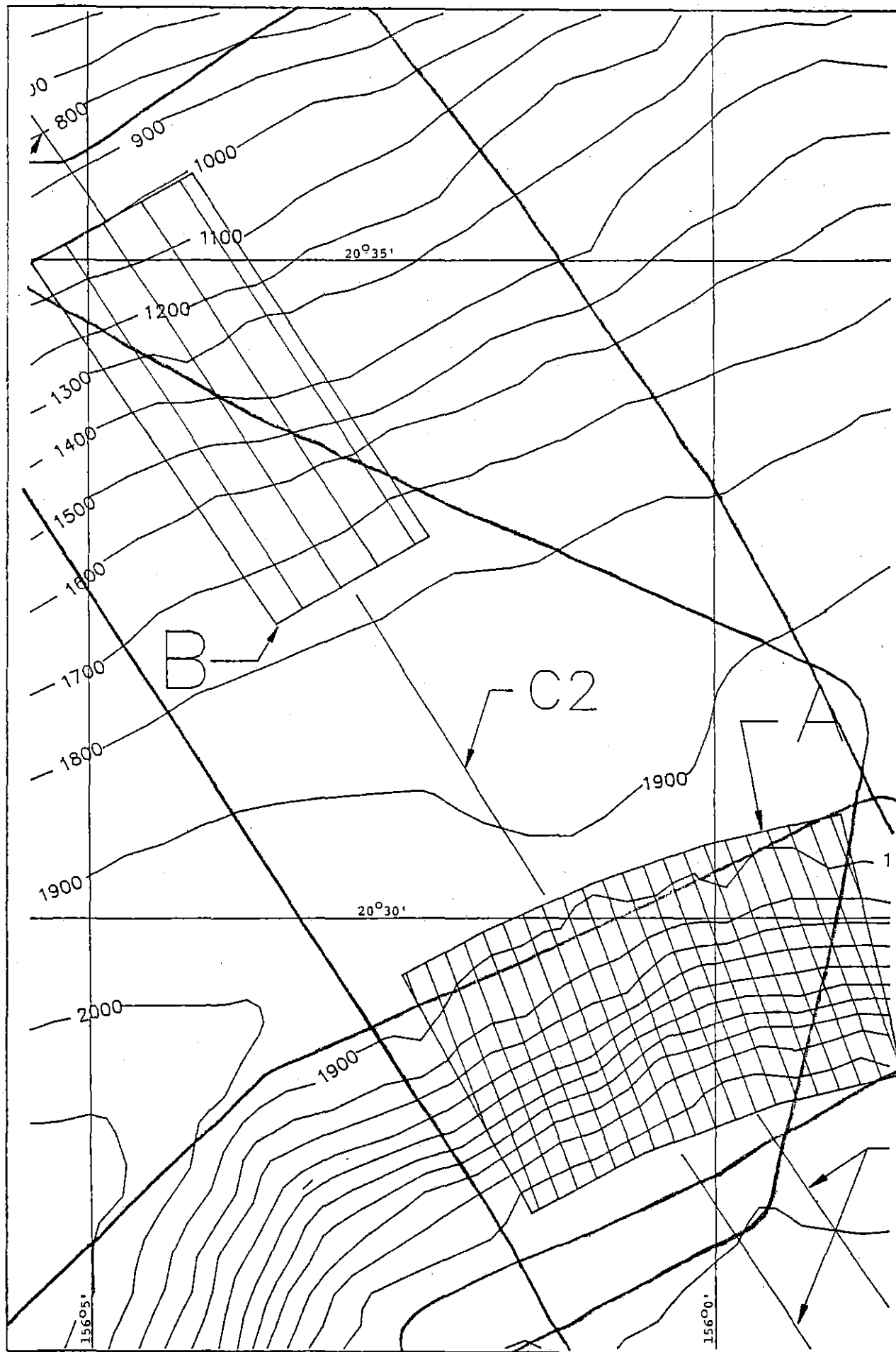


Figure 6: Tow paths followed by SeaMARC side scan system to obtain overlapping and varying views of the survey area

Almost all the tows were conducted either downhill or along a level bottom. Only during the last track was the BRS flown uphill; after the experience of the preceding days, this final uphill track proceeded quite smoothly.

At the end of a given track, the BRS was lifted off the bottom and the MOANA WAVE would proceed at 5 kts to the start of the next track. Cycle times for the BRS were as short as two hours and as long as 18 hours.

During each track, the surface navigation data was recorded digitally on the surface. After the BRS was returned to the deck, the data logger tapes were immediately read and the data checked as quickly as possible. If there were no apparent problems, the BRS was recycled and immediately lowered for another cycle.

The BRS operation required a minimum of four personnel while it was being "flown" over the bottom. A winch operator directly controlled the depth of the BRS and two lab personnel would carefully watch the 12 kHz pinger signal in the lab and communicate directly with the winch operator. A fourth individual would monitor the navigation equipment and ensure that proper monitor displays were provided to the bridge.

During the BRS operations a log was maintained by the lab personnel. This log included the date and time of all significant events, particularly at the start and end of each individual track. The BRS depth, location, ship location, and wire out were routinely recorded.

## 2.3 EQUIPMENT TESTING AND EVALUATION

### 2.3.1 The Bottom Roughness Sampler

The Bottom Roughness Sampler equipment was designed, fabricated, tested and utilized all within a two month period. Because of the relatively short time frame and the extreme importance of reliability and accuracy to this survey, component testing was a vital step in the successful development of this system.

Prior to at-sea operations, the entire instrumentation system was pressure tested to the maximum operating depth of the survey as well as calibration and verification tests of the sensors performed. The echo sounder was tested in a swimming pool over the height range at which it would be operating, 20-40 meters (66 - 131 ft), by orienting the sensor axis parallel to the water surface. In this test, the output of the instrument aimed at a flat vertical wall was read, then smaller and less thick masonry materials were subsequently placed at the center of the beam pattern against the

wall. This test provided very useful information on the resolution of the echo sounder both in terms of its ability to resolve elevation differences and also in the minimum size or area of the object which could be distinguished. For the elevation resolution, tests were only performed down to a 3" thick material (7.6 cm) and the echo sounder repeatedly measured a differential of 3". Although these results are very adequate for the bottom roughness survey, the actual resolution capability of the echo sounder was probably much better than 3". At a nominal distance of about 30 meters and in the center of the beam, the echo sounder was able to resolve a flat rectangular masonry object 15 x 20 cm (6 x 8 inches) with a thickness of 7.6 cm (3 inches).

The objective of a pressure resolution test was to determine the ability of the pressure sensor to resolve a small difference in pressure when the mean pressure was very large. A dead weight tester was utilized to establish a large mean pressure, then the pressure sensor itself was raised in elevation a small amount. The results indicated that the pressure sensor had a resolution capability of  $\pm 0.071$  meters ( $\pm 2.8$  inches) of water depth which was within the resolution specifications for the survey.

A final test of the combined system was conducted on October 24, 1985 during a one-day shakedown cruise on the MOANA WAVE. The BRS was lowered to 2000 meters and towed along the bottom. During this cruise, problems arose with the bottom acoustic positioning and the echo sounder. It was felt that the acoustic transponder difficulty was related to the lack of an adequate surface transducer which had been delayed in shipment and not yet arrived in Honolulu. The problem with the echo sounder proved to be a faulty solder connection in a capacitor. This electronic problem was determined after the cruise and was corrected with sufficient confidence that the survey cruise was not delayed.

The final testing of the equipment was during the cruise itself and proved to be the most convincing that the entire system was performing to the desired specifications. Figure 7 illustrates a representative profile of the Kohala slope taken during the cruise. This profile was plotted as a function of time with each horizontal division corresponding to 10 minutes or approximately 450 m. The upper trace is the echo sounder data and represents the elevation of the BRS above the bottom. The second trace is from the pressure transducer and illustrates the depth of the BRS. The lower trace is the sum of the pressure and echo sounder distances and represents the true bottom. Note that the pressure transducer clearly shows each individual lowering of the BRS by the winch operator. Note also that there is some noise in the bottom profile data. Each of these downward spikes represents one data point from the echo sounder that was high because the echo sounder did not hear the return echo. These spikes generally occurred more frequently in the areas more prone to sediment covering; the noise level represented here did not present a problem with data analysis.

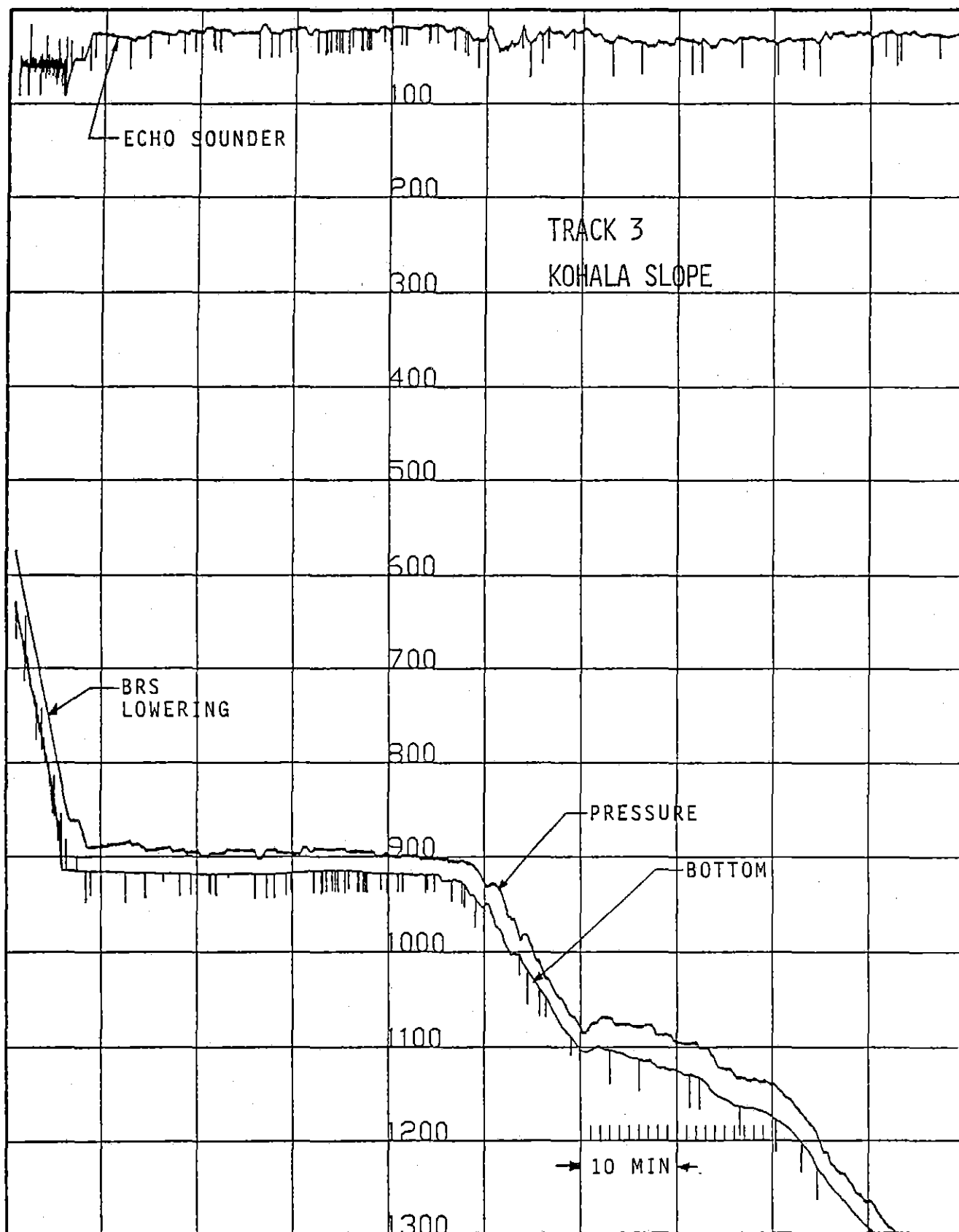


FIGURE 7: Typical BRS data showing the pressure, altitude, and bottom data.

The detail contained in the bottom roughness data cannot be readily seen in Figure 7. Over 15,000 data points are used to generate this illustration. An expanded track is illustrated in Figures 8 and 9. Here some of the detail is apparent in both the pressure and the echo sounder data. The BRS shows strong vertical movement because of the heave of the MOANA WAVE but this motion is completely taken out through the echo sounder data and, in some cases, the bottom is seen to be perfectly smooth. This was the primary method of checking the accuracy and timing of the pressure transducer and echo sounder signals. When the two independent and widely varying signals can be added to produce a smooth bottom the BRS is performing well.

Figure 10 represents further detail on the bottom roughness where each individual data point can be observed. This data is along the Kohala Slope and represents a major rock outcrop.

The bottom roughness sampler was not, however, operated without problems. At one point the data logger batteries shorted and 12 hours of towing had to be repeated. In another series of tracks the echo sounder became intermittent and would provide a mixture of correct returns mixed with incorrect but high elevation values. This proved to be the symptom of a poorly soldered circuit board. Once the intermittent resistor was located, the echo sounder functioned well. Figure 11 illustrates the data received when the echo sounder was providing intermittent data. Note that while the bottom profile appears quite noisy, the upper margin of this profile follows very closely the actual bottom contours and, in spite of the many errors, the bottom bathymetry can be easily observed.

### 2.3.2 MOANA WAVE Equipment

All the equipment on the MOANA WAVE was tested during the shakedown cruise of October 24. The winch, BRS handling gear, bathymetry, pingers and lab equipment all worked well throughout the entire cruise.

### 2.3.3 Navigation Equipment

The primary Trisponder navigation equipment was tested by the supplier (Sci-Tech) prior to the cruise but not calibrated. During the cruise it was calibrated relative to the Mini-Ranger backup system which had been calibrated. There were some problems with the loss of shore navigation stations due to battery problems, positioning problems with the receiver antenna on the MOANA WAVE and, finally, the entire loss of electrical power on Maui for several hours. For the relatively short period of time that surface navigation was not available, the vessel used GPS very successfully.

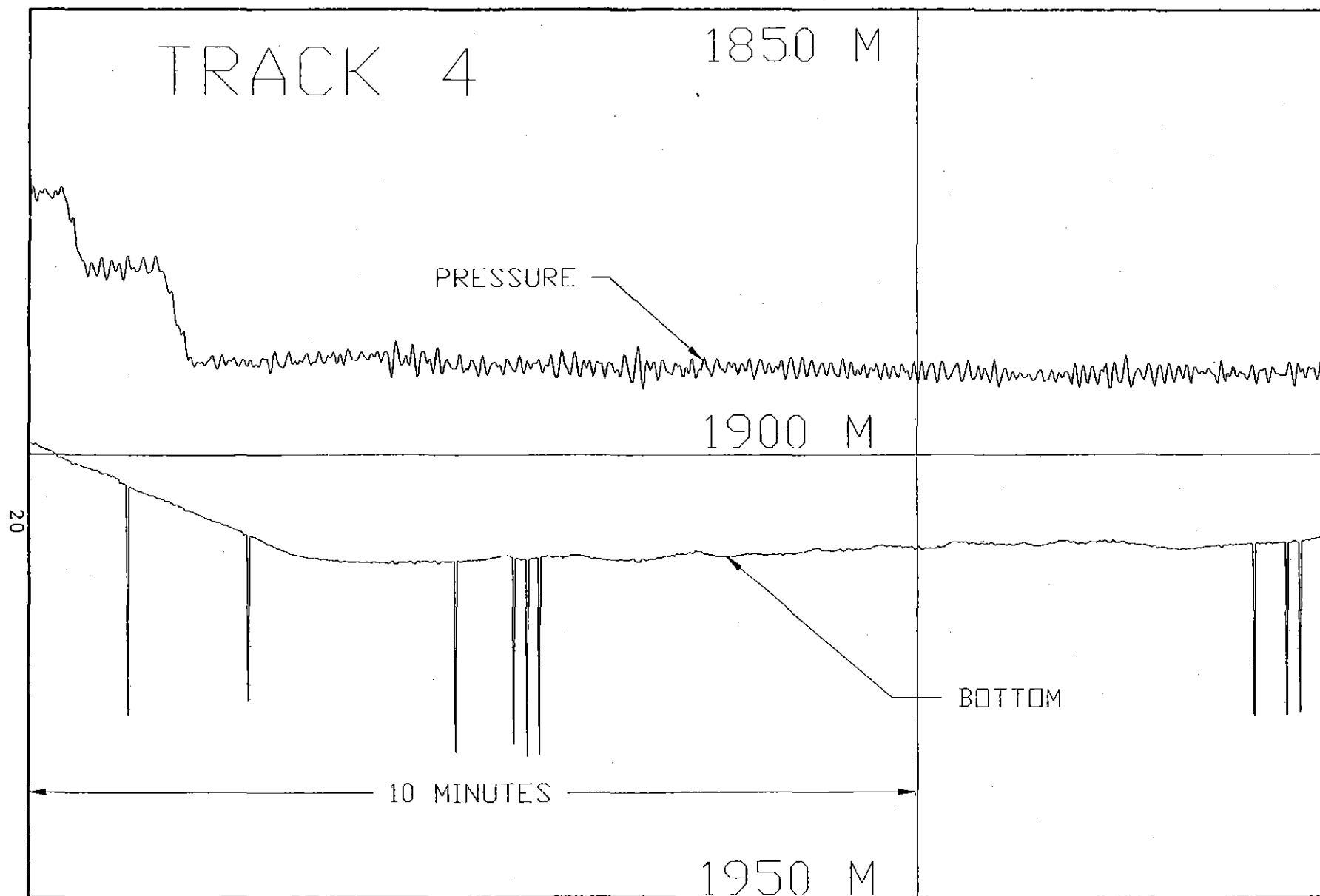


FIGURE 8: Track 4 at the base of the Kohala Slope illustrating the BRS movement due to vessel heave and the relatively smooth bottom. Spikes in the bottom are caused by unreturned echos in the profiler.

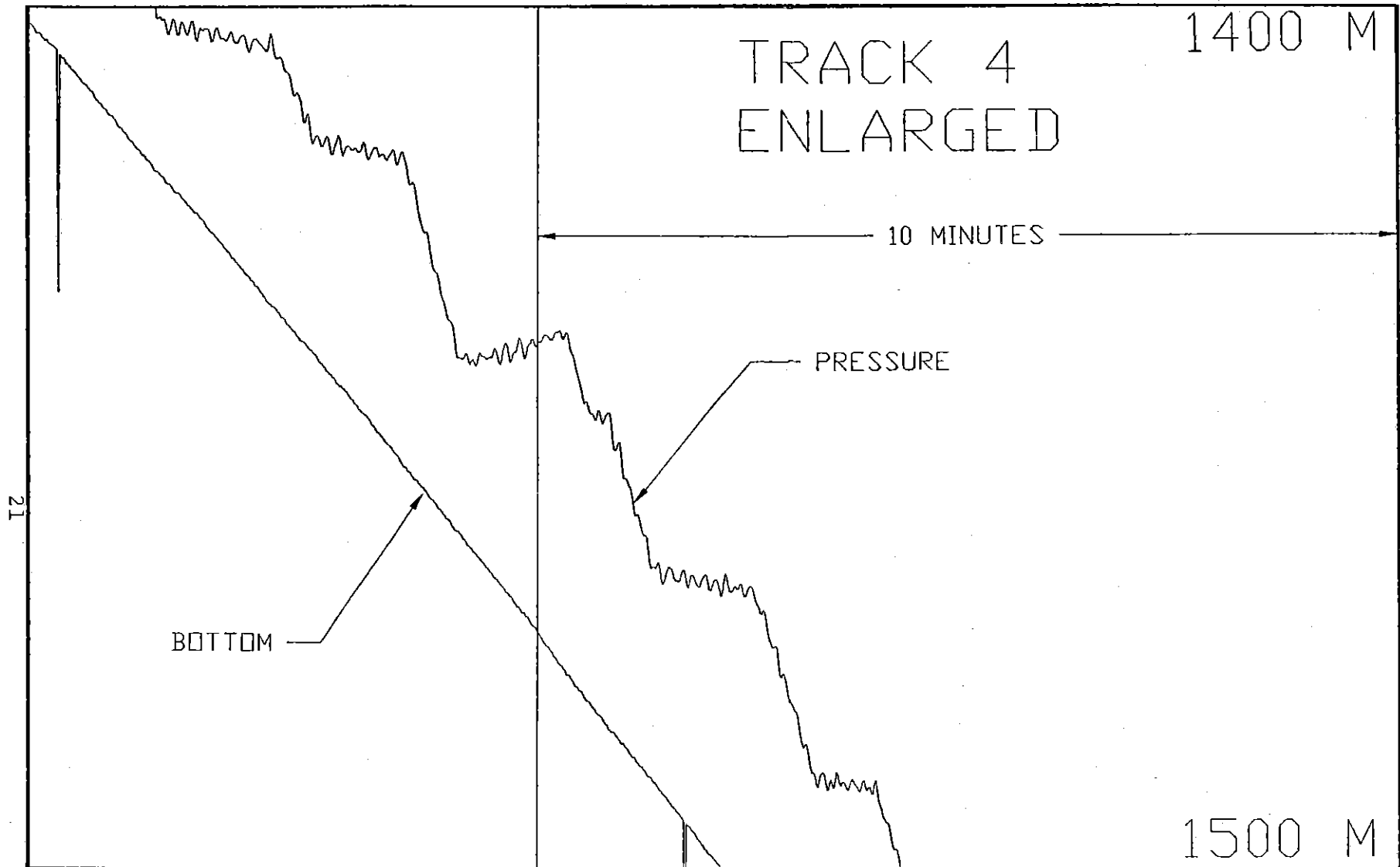


FIGURE 9: Track 4 along Kohala Slope between 1400 and 1500 m.  
Note the step lowering of the BRS and the very smooth bottom.

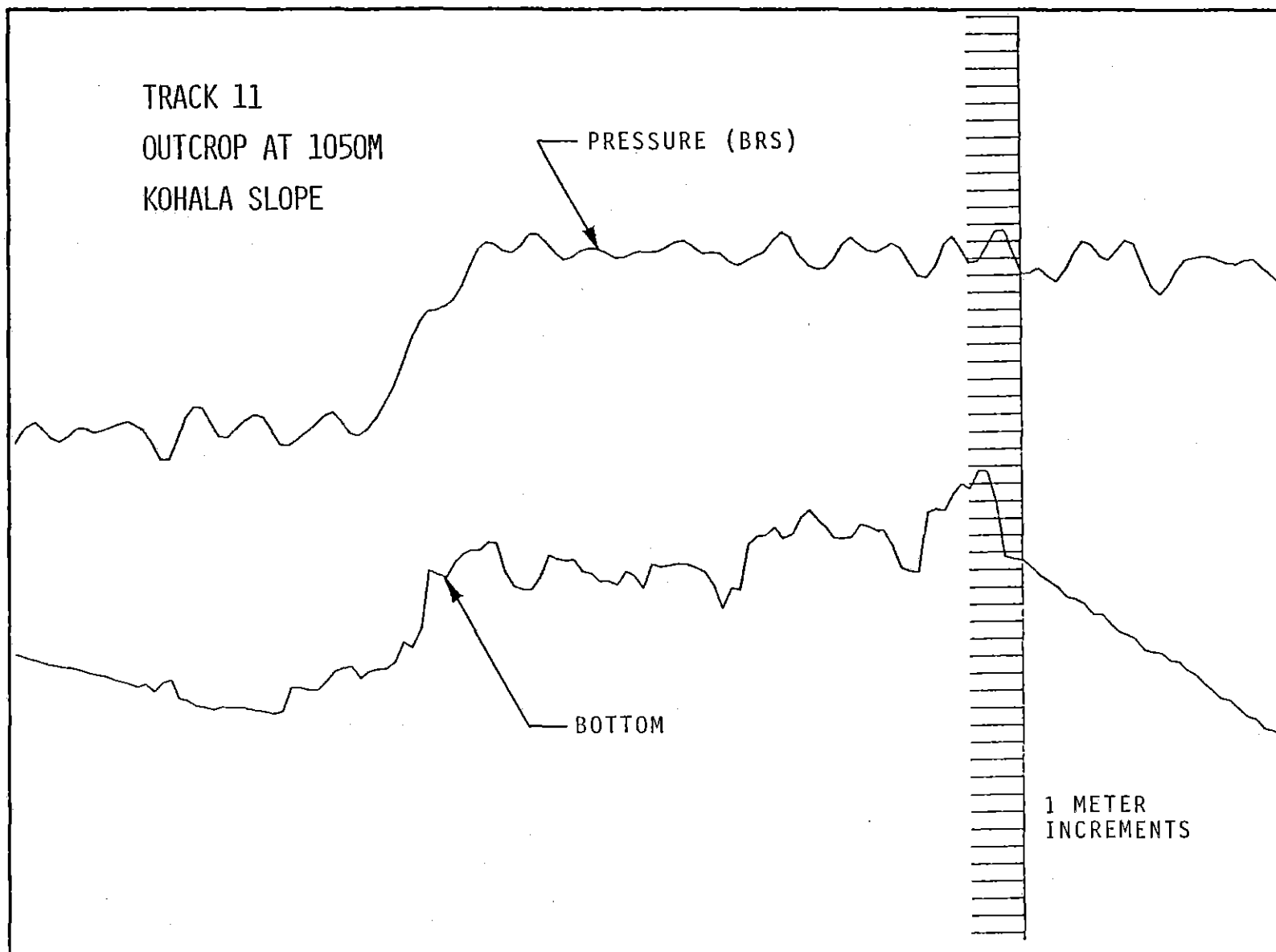


FIGURE 10: Outcrop on Kohala Slope at 1100 m. Note individual data points.  
The horizontal scale equals the vertical scale.



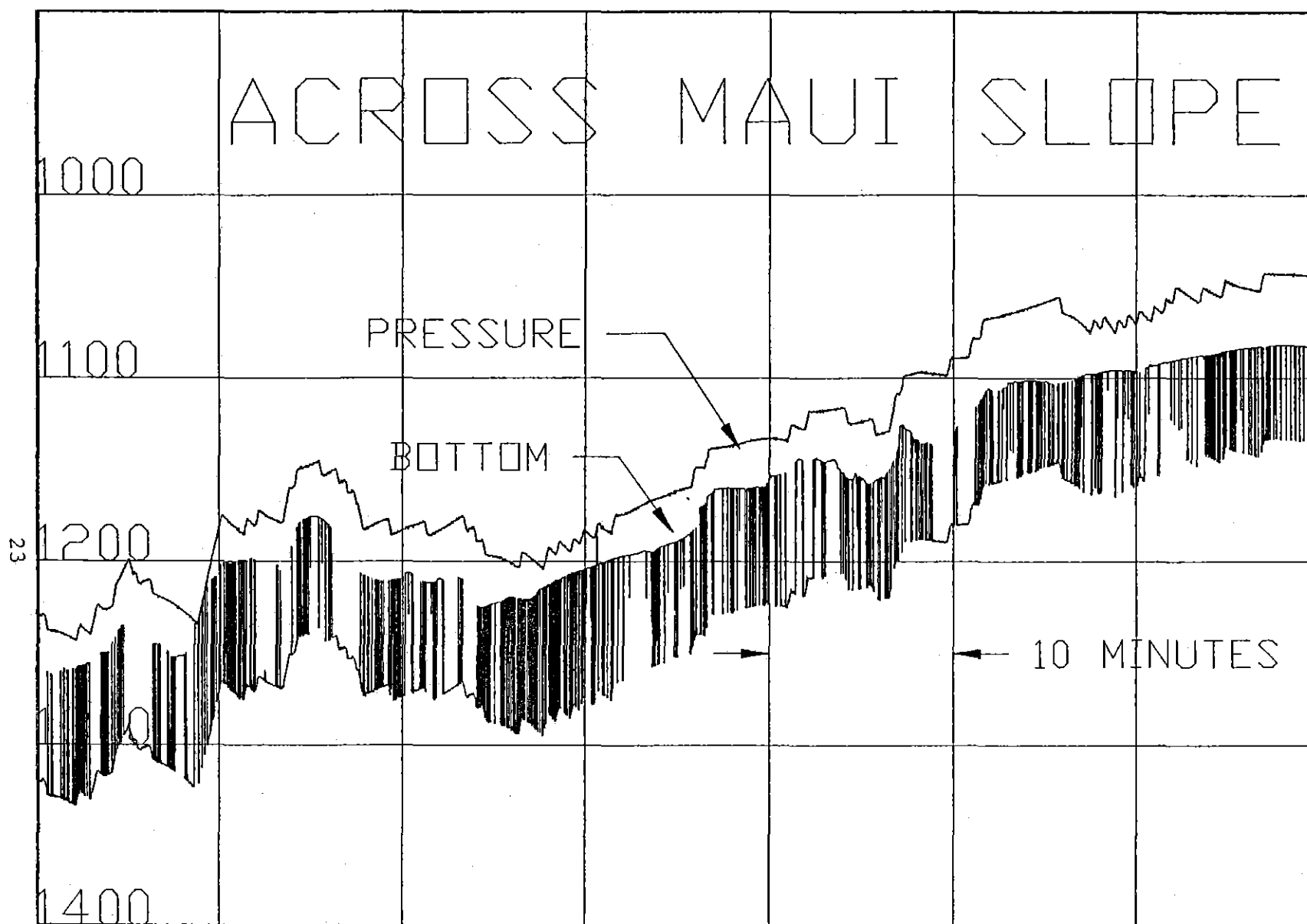


Figure 11: BRS data with an intermittent echo sounder. Bottom profile data is still obtained in spite of a significant loss of data points.

The underwater long based navigation equipment had few tests prior to the cruise by the supplier primarily due to logistics problems associated with assembling a number of transponders in Hawaii. When tested on deck, all the components individually checked out correctly. When placed in the water, however, the transponder on the BRS would not communicate with the other transponders properly and would only infrequently respond to a direct ship ranging. Even when the BRS transponder was placed on the cable above the steel BRS frame and the 12 kHz pinger was removed (it was believed that there was a possible interference), the system did not perform. This was the only complete equipment failure during the whole cruise and fortunately it only slightly adversely affected the quality of the data.

## 2.4 DATA ANALYSIS PROCEDURES

### 2.4.1 Bottom Roughness Data

The bottom roughness data logger records pressure, altitude and time at each second. On a typical track, over 5000 data points would be collected, each with pressure, altitude and time. For the entire cruise, 300,000 bathymetric data points were collected.

Once the digital tape was removed from the data logger it was dumped directly into one of the WANG PCs. The hexadecimal data was immediately checked for consistency and a reasonable range, particularly the last data taken in the most recent track. Finally, the total size and length of the record would be checked to ensure that all the data was recorded. At that point, the data logger would receive new batteries, new tapes and be placed on the BRS for another lowering.

The second step in handling the BRS data was to translate it from the hexadecimal into engineering units for the pressure (depth), altitude and bottom depth for each data point. The time would be corrected to GMT and the pressure and depth data plotted on a large 24x36" plot. This large plot would then serve as an immediate feedback on the bottom roughness and, in addition, on the performance of the BRS electronics. Figure 7 is an example of these plots.

### 2.4.2 Ship Position Data

The MOANA WAVE position and time were recorded by a 9826 Hewlett Packard computer onboard the ship. Once a particular track was run, the navigation data would be transferred from the 9826 into one of the WANG PCs. In addition to the position and time data, the 9826 provided range data and other information which made the sorting and data processing rather difficult. This processing was not accomplished onboard the ship, but was completed several

weeks after the cruise. The final information gathered from the navigation system was the position of the ship (X,Y) versus time at 10 second increments.

#### 2.4.3 Combining BRS and Positional Data

The final processing of the raw data involved combining the BRS data record with the position record. The original plan for the survey involved recording the X,Y position of the BRS utilizing the long-based underwater acoustic navigation system. This system failed to operate and the only positioning available was for the MOANA WAVE. It was possible to approximately correct the ship position to the BRS position. Several tracks were made with the BRS at various velocities and with known cable lengths and BRS depths. From these various runs, it was possible to determine a correlation between the BRS distance aft of the MOANA WAVE as a function of the depth and velocity squared:

$$C = (0.86Z - 469) V^2 \quad (\text{meters})$$

The above values are a best fit solution for a variety of cable lengths, speeds, and depths from selected runs between 900 m and 1900 m in depth. Typical deflections aft are between 250 m and 900m at 0.75 m/s velocity. This is an approximate correction with a probable error of 10 to 15%; its primary purpose is to approximately adjust adjacent tracks relative to each other, such that features seen in parallel tracks can be better positioned.

The above correction was applied to the navigational data in terms of a time correction. With the BRS data, a polynomial was generated for depth as a function of time. From the navigation data, a polynomial was generated for speed of the vessel (and the BRS) as a function of time. By assuming that the BRS follows the ship path, which is correct most of the time because the MOANA WAVE followed the planned course very well, and assuming the ship maintained a reasonably constant speed (also correct most of the time) a relatively simple time correction can be applied to the navigation data in the form of:

$$dT = (.86Z(t) - 469) V(t)$$

Where  $Z(t)$  and  $V(t)$  are polynomials and a function of time. It was then possible to apply a time correction as a function of time to the navigation data.

#### 2.4.4 Bottom Roughness Impact on the Cable

The final measure of impact of bottom roughness on the Hawaii Deep Water Cable is determined by analytically laying a cable over the measured profiles and computing the lengths of the

resultant free spans and the associated bend radii. Because of the very large quantity of data gathered for determining the bottom roughness and because only the more elevated data points affect the cable shape and spans, the cable program makes successive approximations of spans before utilizing a detailed analytic cable solution.

The first approximation can be visualized as rolling a ball along the bottom roughness data. The first approximation of cable contact points is made when the ball contacts two data points. The ball is 'rolled' one more step to get an approximation for the next span, which is used in determining an approximate end condition for the current one. A more exact solution for the span is then calculated, knowing the span length and the approximate cable angle at each of the contact points. This more exact solution is compared to the bottom bathymetry between the contact points to ensure that it is indeed a valid cable span. If not, new intermediate contact points are determined and the process is repeated. Once a clear span is determined, the bend radius at either end of the span is also computed. If the span is of excessive length, as determined by Pirelli's criteria for critical span length as a function of the laying tension, it is tabulated as an unacceptable or critical span. If the bend radius is less than 1.5 m, it is also tabulated as an unacceptable span for reasons of bend radii.

This analysis gives an estimation of cable touchdown points and subsequently, spans and bend radii, based primarily on Love's equation (Reference 4). This method, although complex, is only an approximate solution to the differential equations modeling a laid cable. A comparison of selected analytic results with scale model predictions are included in the appendix.

Figures 12 and 13 illustrate spans for a cable laid along a typical section of bottom roughness profile, at different tensions. The raised line is a representation of the cable spans (straight lines) elevated slightly above the bottom for clarity. The higher tensions give slightly longer spans, often contacting different end points than the lower tensions.

#### 2.4.5 Spectrum Analysis

A spectrum analysis has not been done on the Bottom roughness data for the preliminary survey. A tabulation of unacceptable spans and bend radii has been sufficient to evaluate the bottom roughness problem. A spectral analysis of the bottom roughness is a valuable tool, however, and may be valuable in the evaluation of the final roughness, depending upon the type of cable laying solutions that are selected. A spectrum analysis can determine statistically the number of unacceptable spans or bend radii that may be encountered when laying a cable in a region of

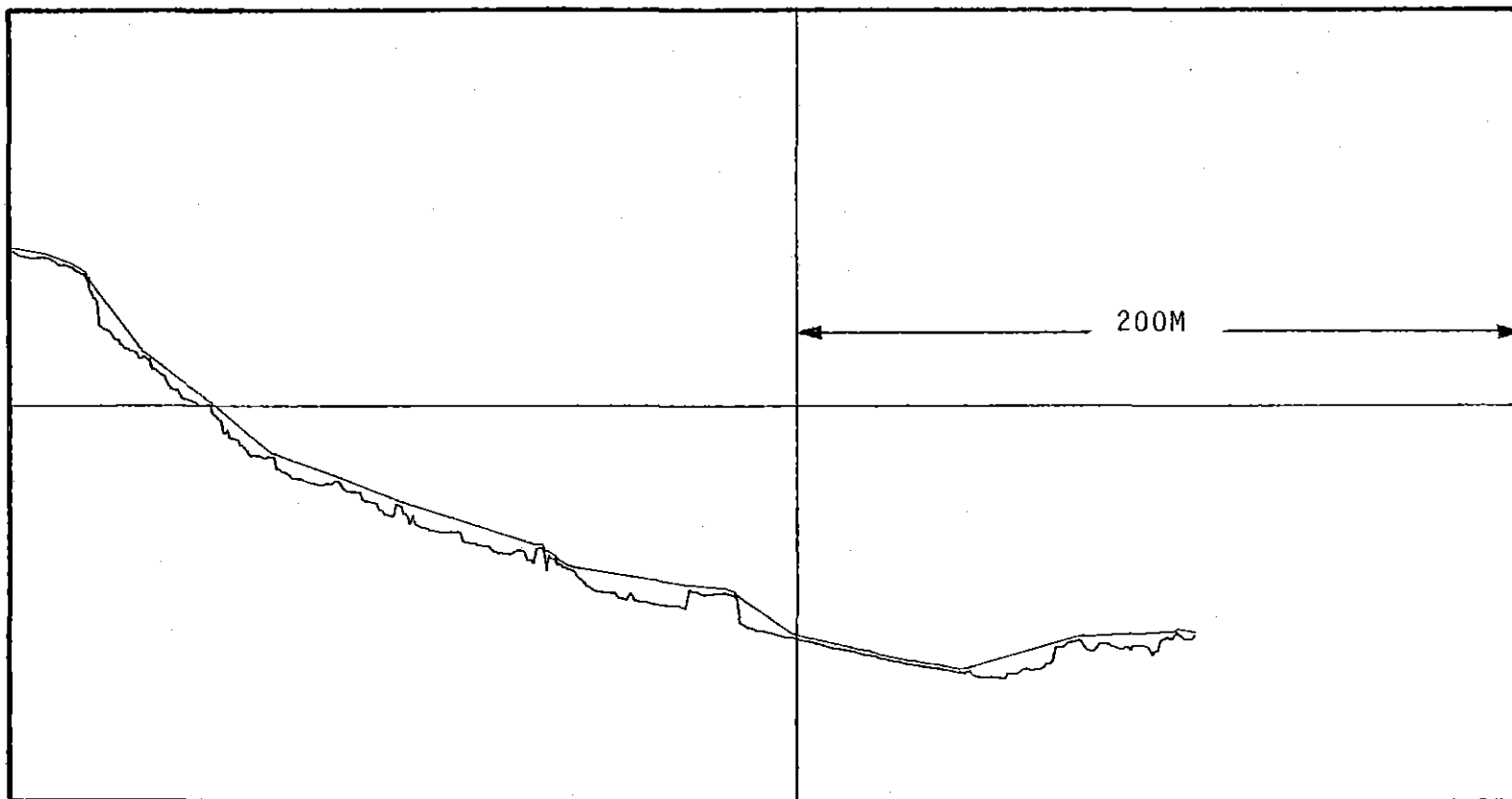


FIGURE 12: Representation of cable spans over a rough bottom,  
cable laid at 3000 kg.

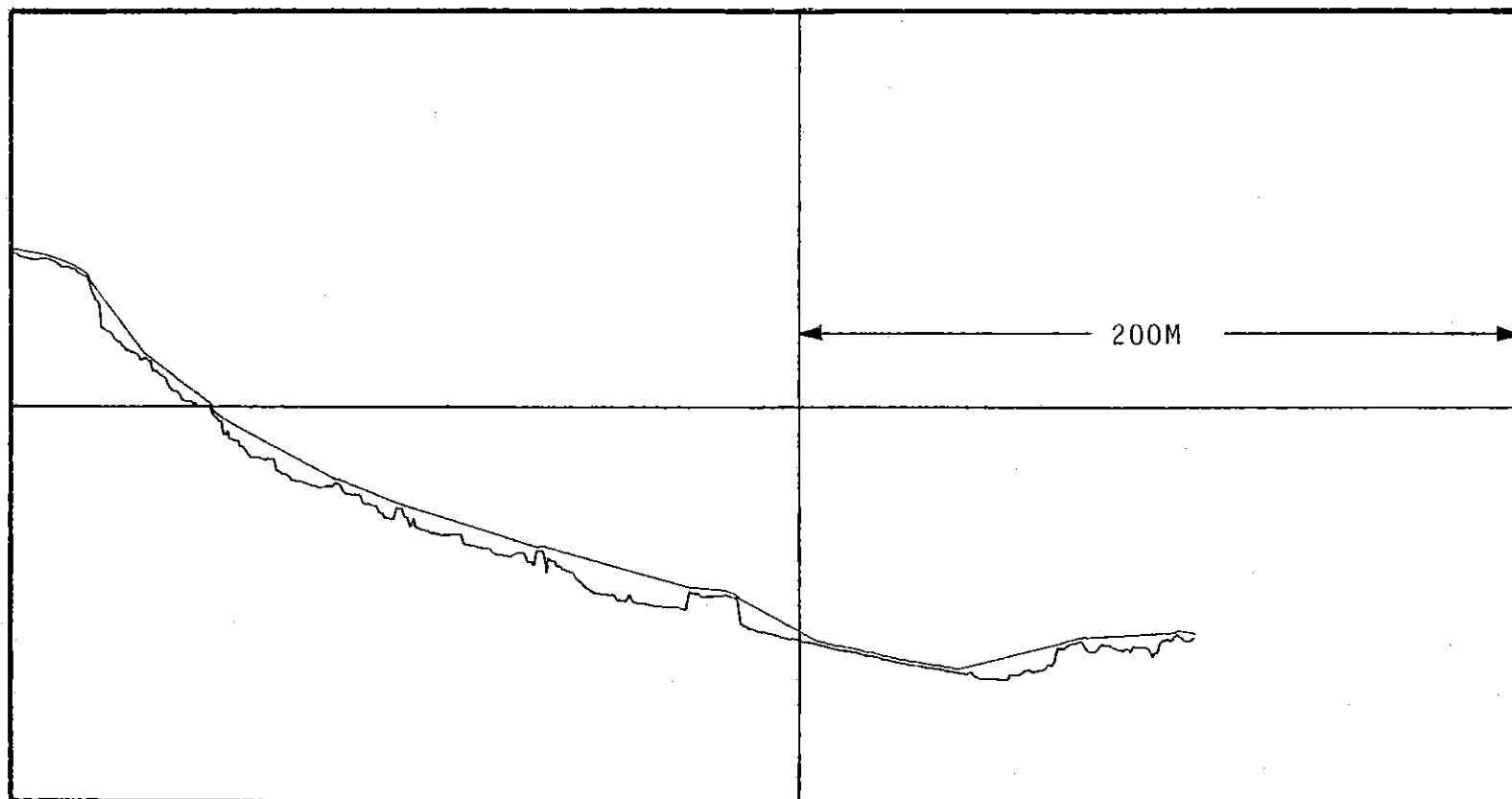


FIGURE 13: Representation of cable spans over a rough bottom,  
cable laid at 5000 kg.

given bottom roughness. It is not desirable to lay the cable exactly along any given surveyed route since that survey is along a path which is only 1-1/2 meters wide. A cable laid, for example, with a 30 m accuracy, would in all probability be laid to either the right or the left of this previously measured path and such a deviation would be associated with a finite probability of encountering an unacceptable span or bend radii. A spectral analysis is valuable in determining this probability and therefore computing the probable costs and difficulty of laying the cable.

#### 2.4.6 Data Storage

The digital data for the Bottom Roughness Survey is stored at a variety of locations and on different media. The BRS tape records from the data logger, digital cassette tapes, are being stored by E.K. Noda & Associates. The ship positional data on both HP 9826-compatible disks and on MS DOS disks are being stored by Makai Ocean Engineering. The final processed raw data giving the position, depth and time for each survey track is also being stored by Makai Ocean Engineering on MS DOS double sided, double density 5-1/4" floppies.

### 3. RESULTS

#### 3.1 SURVEY TRACKS

Figure 14 illustrates the planned survey tracks for the bottom roughness survey. Extensive coverage included areas A, B and C. Additionally, the survey was extended to get at least one track all the way from Hawaii to Maui, at least within the range of the electronic positioning system.

The selection of track location was made primarily based on SeaMARC data and preliminary analysis of BRS data as it became available. For example, when operating in the Kohala Slope area, Area A, it was quickly observed that the most severe area was at the top of the slope and that the mid and bottom portions of the slope were relatively smooth. Most of the tracks then concentrated in the upper slope region. Similarly, tracks run on the Maui side together with SeaMARC data indicated that there was a probable route to the west of Area B. As a result, Tracks 41, 42 and 43 were run slightly to the west and located between apparent obstacles observed with the SeaMARC side scan system.

Figure 15 lists all 45 tracks conducted during this survey. A total of 211 kilometers were surveyed. Thirty km of this data did not provide good roughness data, either because of a short in the echo sounder (Tracks 1 and 2) or a short in the data logger batteries (Tracks 6, 7, 8, 9). The total success rate was 86% with a total of 181 km of good bottom data.

Figure 16 is a plan view of the actual BRS tracks for which the navigation data was adequate and which, upon reviewing the raw data, looked promising as cable routes. Note that the cross Maui tracks and the east Kohala tracks were not processed because they are least likely cable path candidates. These tracks include the correction to estimated BRS position as previously discussed.



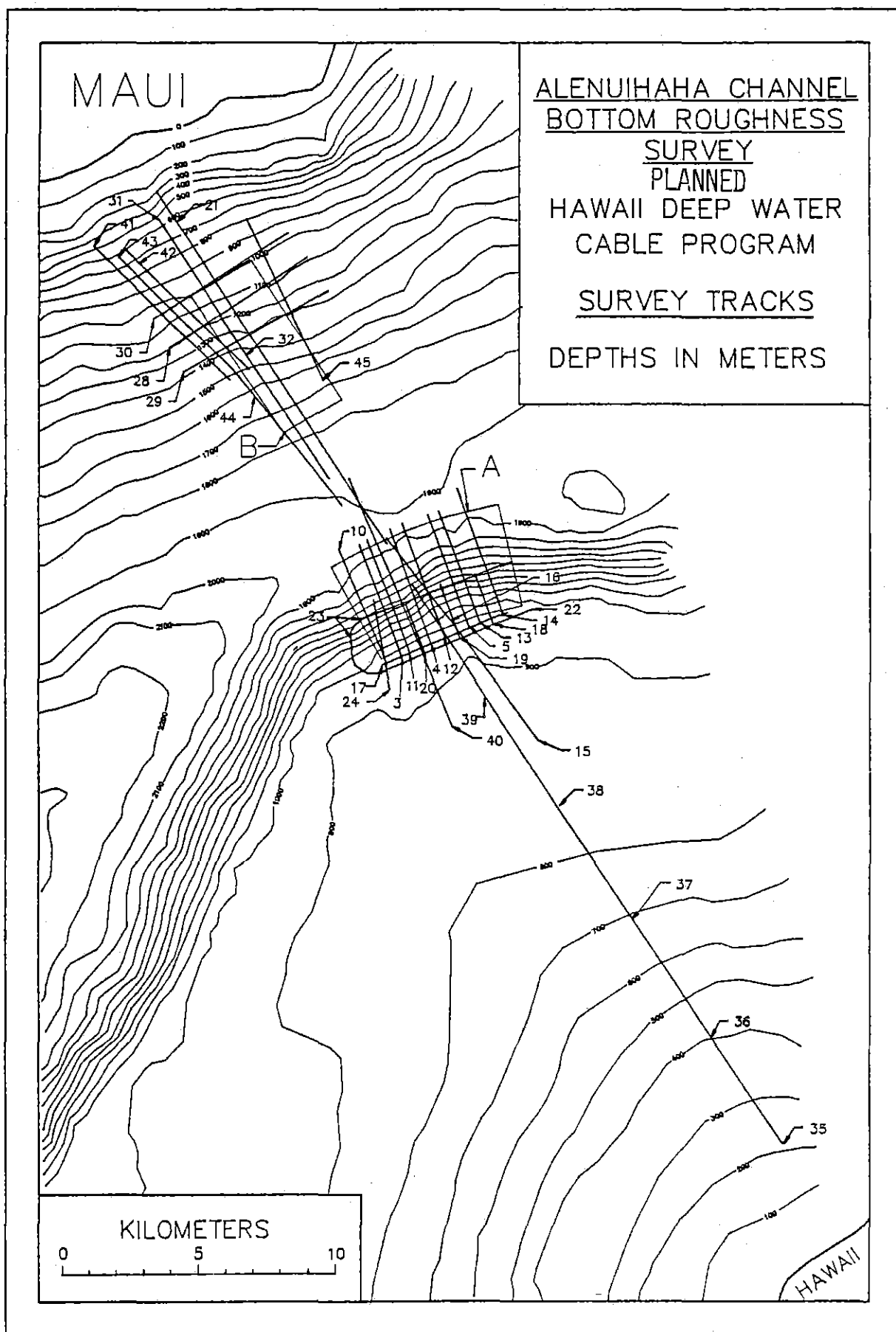


Figure 14.

ALENUHAHA CHANNEL SURVEY, HDWC PROGRAM

PLANNED TRACKS

Figure 15

TRACK #	AREA	STARTING POSITION		END POSITION		MISSION	BOT NAV?	BRS OK?	TOP NAV?	OK?	86% 14% DONE FAIL			
		X	Y	X	Y						KM	KM	KM	TOTAL
											211.4	181.	30.2	
1	A	219780	14100	224000	15780	1	NO	NO	FAIR	0	4.5	0.0	4.5	Echo Sounder failure
2	A	224000	15780	221750	21850	1	NO	NO	YES	0	6.5	0.0	6.5	Echo Sounder failure
3	A	220100	14550	218620	18570	3	NO	YES	Fair	1	4.3	4.3	0.0	
4	A	221200	15000	219700	19130	4	NO	YES	YES	1	4.4	4.4	0.0	
5	A	222570	15650	221100	19670	5	NO	YES	YES	1	4.3	4.3	0.0	
6	A	223870	16000	221700	21850	6	NO	NO	YES	0	6.2	0.0	6.2	New Transponder
7	A	223000	15750	221500	19800	6	NO	NO	YES	0	4.3	0.0	4.3	
8	A	221670	15300	220150	19350	6	NO	NO	YES	0	4.3	0.0	4.3	
9	A	220400	14700	218900	18750	6	NO	NO	YES	0	4.3	0.0	4.3	Data Logger batteries short, lose 6-9
10	A	219600	14250	217900	18350	10	NO	YES	YES	1	4.4	4.4	0.0	11.5 kHz pinger added
11	A	220400	14700	218900	18750	10	NO	YES	YES	1	4.3	4.3	0.0	
12	A	221670	15300	220150	19350	10	NO	YES	YES	1	4.3	4.3	0.0	Pinger weak
13	A	223000	15750	221500	19800	13	NO	YES	YES	1	4.3	4.3	0.0	11.0 kHz pinger added
14	A	223870	16000	222150	20630	13	NO	YES	Fair	1	4.9	4.9	0.0	lose shore navigation midway
15	A	225150	11500	222350	15250	13	NO	YES	NO	1	4.7	4.7	0.0	GPS, manual plot
16	A	222350	15250	219580	18820	13	NO	YES	NO	1	4.5	4.5	0.0	GPS, manual plot, lose @ end
17	A	219400	14200	224000	16100	17	NO	YES	YES	1	5.0	5.0	0.0	Transponder on
18	A	223500	15650	222825	17500	17	NO	YES	YES	1	2.0	2.0	0.0	short 2 km
19	A	222250	15200	221550	17100	17	NO	YES	YES	1	2.0	2.0	0.0	short 2 km
20	A	221000	14600	220300	15350	17	NO	YES	YES	1	1.9	1.9	0.0	short 2 km
21	B/C	211200	31550	219600	18600	21	NO	YES	YES	1	15.4	15.4	0.0	Long, 15 km
22	A	224920	16220	219535	14010	22	NO	YES	YES	1	5.8	5.8	0.0	
23	A	218600	15830	224160	17955	22	NO	YES	YES	1	6.0	6.0	0.0	
24	A	219700	13340	219130	16570	22	NO	YES	YES	1	3.3	3.3	0.0	
25	B	211870	29558	217500	21000	25	NO							Aborted, high winds
26														Cancel, high winds
27														Cancel, high winds
28	B	211700	25800	216700	29100	23	NO	fair	YES	1	6.0	6.0	0.0	Cross tows
29	B	212200	24900	217450	27900	23	NO	fair	YES	1	6.0	5.0	0.0	Cross tows
30	B	211100	26850	216000	30000	23	NO	fair	YES	1	5.8	5.8	0.0	Cross tows
31	B	211300	30500	214500	25500	23	NO	fair	YES	1	5.9	5.9	0.0	Repeat of 25
32	B	214500	25500	217500	21000	23	NO	fair	YES	1	5.4	5.4	0.0	Repeat of 25
33	A	223200	15450	221470	14772	33	NO							w/o pinger, flat run
34	A	220650	15430	219000	20000	33	NO							speed and Cd calculation
35	C3	234000	-3300	231560	400	25	NO	YES	YES	1	4.4	4.4	0.0	N Kohala run
36	C3	231560	400	229120	4100	25	NO	YES	YES	1	4.4	4.4	0.0	N Kohala run
37	C3	229120	4100	226680	7800	25	NO	YES	YES	1	4.4	4.4	0.0	N Kohala run
38	C3	226680	7800	224240	11500	25	NO	YES	YES	1	4.4	4.4	0.0	N Kohala run
39	C3	224240	11500	220600	17100	25	NO	YES	YES	1	6.7	6.7	0.0	N Kohala run
40	A	222000	12000	218250	21000	25	NO	YES	YES	1	9.8	9.8	0.0	Added winch cable vs pressure test
41	B	208900	29500	213900	24600	26	NO	YES		1	7.0	7.0	0.0	Maneuver around SeaMarc?
42	B	210110	29310	214600	25000	26	NO	YES	fair	1	6.2	6.2	0.0	Maneuver around SeaMarc?
43	B	209800	29100	214000	25000	26	NO	YES		1	5.9	5.9	0.0	Maneuver around SeaMarc?
44	B	214000	25000	218000	20000	26	NO	YES		1	6.4	6.4	0.0	Maneuver around SeaMarc?
45	B	214500	30500	217300	24600	26	NO	YES		1	6.5	6.5	0.0	Maneuver around SeaMarc?

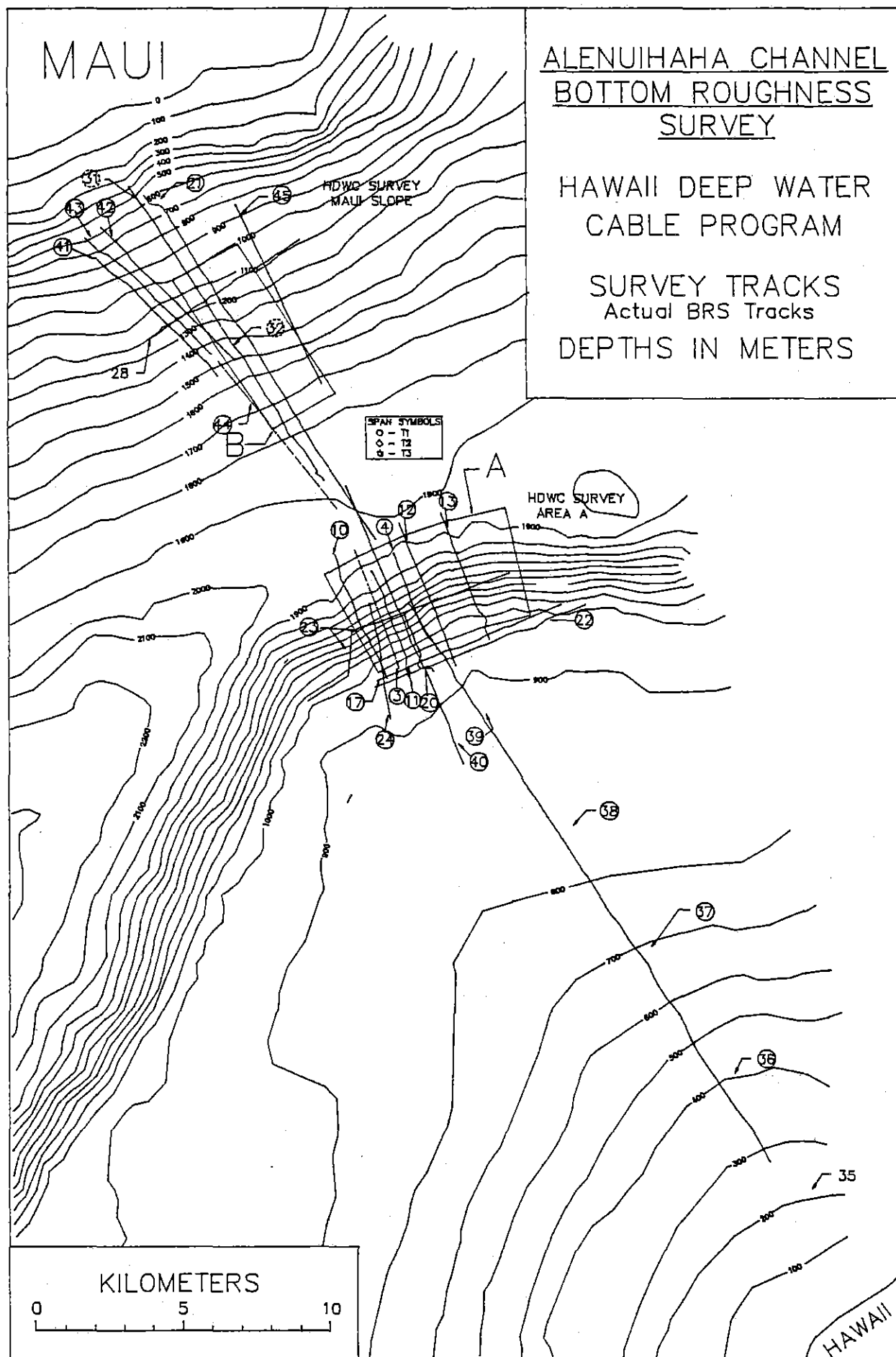


Figure 16

## 3.2 UNACCEPTABLE SPANS AND BEND RADII

Each of the BRS tracks that had potential for a cable route were processed to determine the extent of unacceptable cable spans and bend radii, if a cable were to be laied down that path. By this means and by plotting the location of the unacceptable spans both in the plan and profile views, the roughness was evaluated and patterns, if they exist, could be determined.

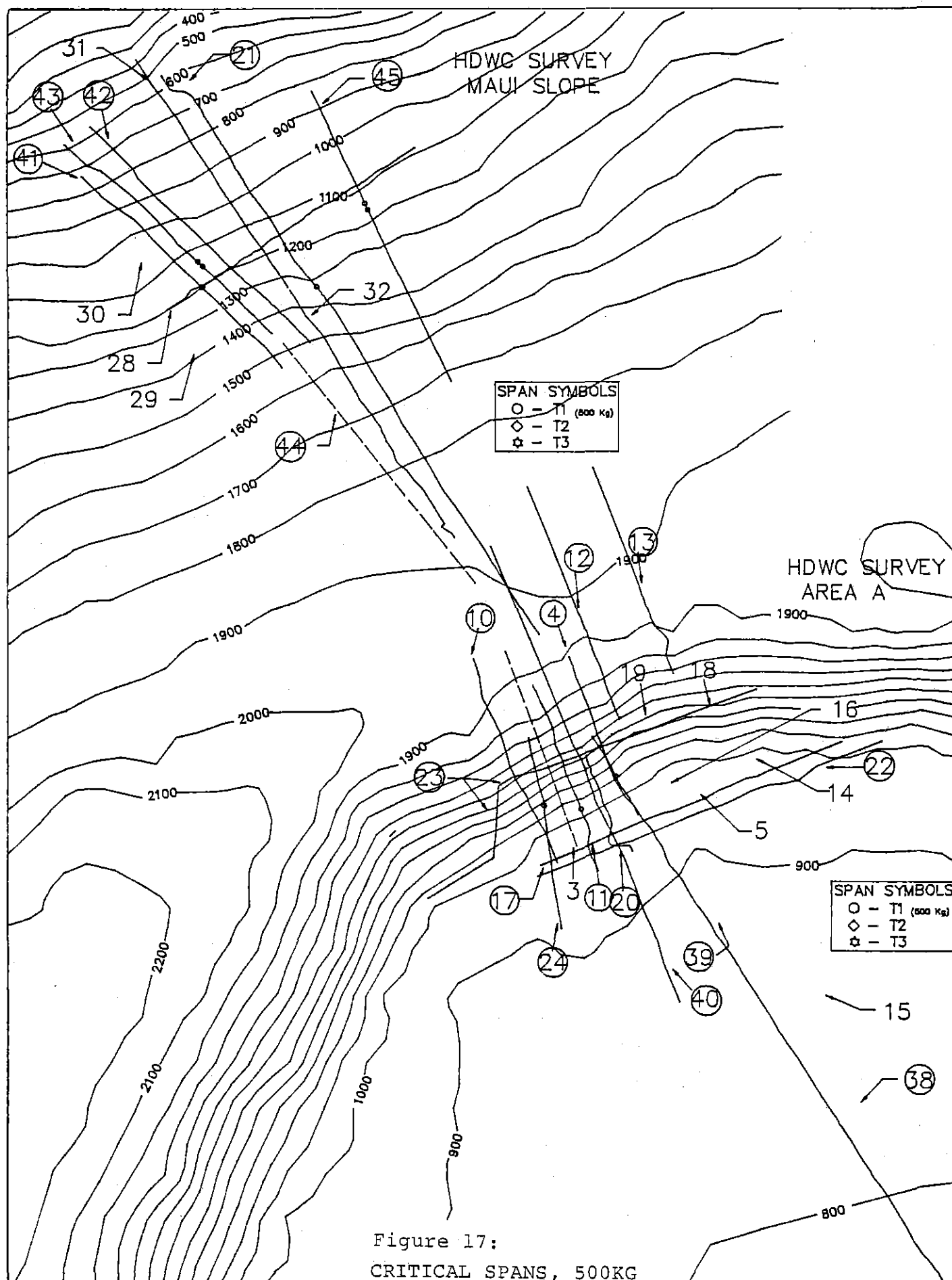
The critical bend radius, to prevent cable kinking, is noted to be 1.5 meters, independent of tension. The critical cable span, being a product of dynamic fatigue analysis, is strongly a function of bottom tension and cable properties, and ranges from 20 meters to 60 meters for the tensions analyzed.

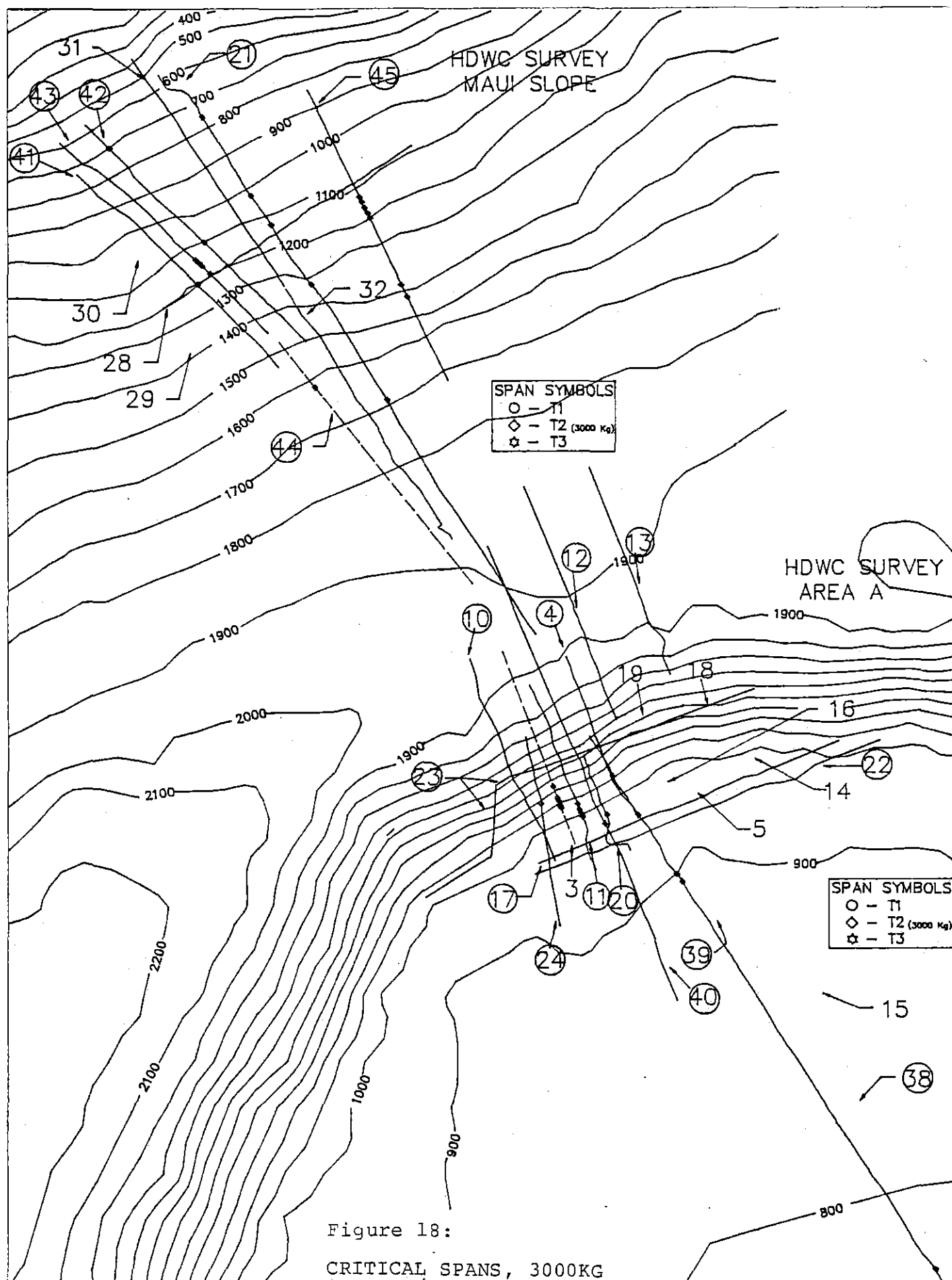
Figures 17 through 19 display the locations of critical spans at 500, 3000 and 5000 kg bottom cable tension, respectively, as analyzed from the track profiles. Figure 20 is a summation of critical spans for all three tensions, and shows the general areas of inhibitive roughness by the congregation of spans, under all tensions evaluated. Figure 21 is a tabular summation of all the cable spans, and the cable span frequency of occurence, for all the tracks analyzed under varying cable tensions. Note that the span distribution varies widely from track to track indicating different levels of bottom roughness.

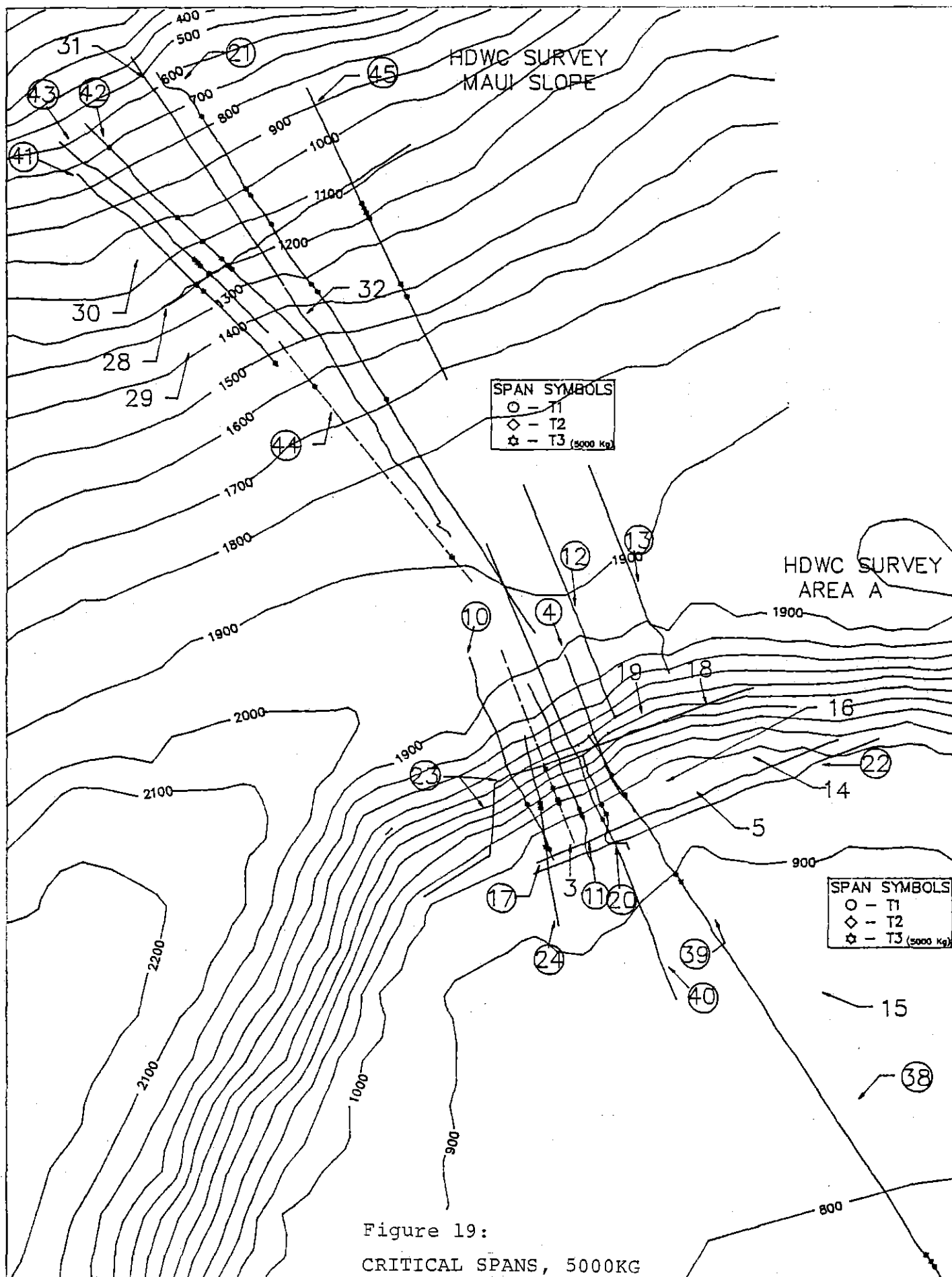
One of the key concerns prior to this survey was whether wide escarpments or faults existed barring any passage of a cable. This does not appear to be the case, judging by the scatter in the span locations and by reviewing the profiles. The one area of concentrated unacceptable spans is at the top of the Kohala slope, near the 1000 m contour. Some paths, however, pass through this area without spans at the lower tensions.

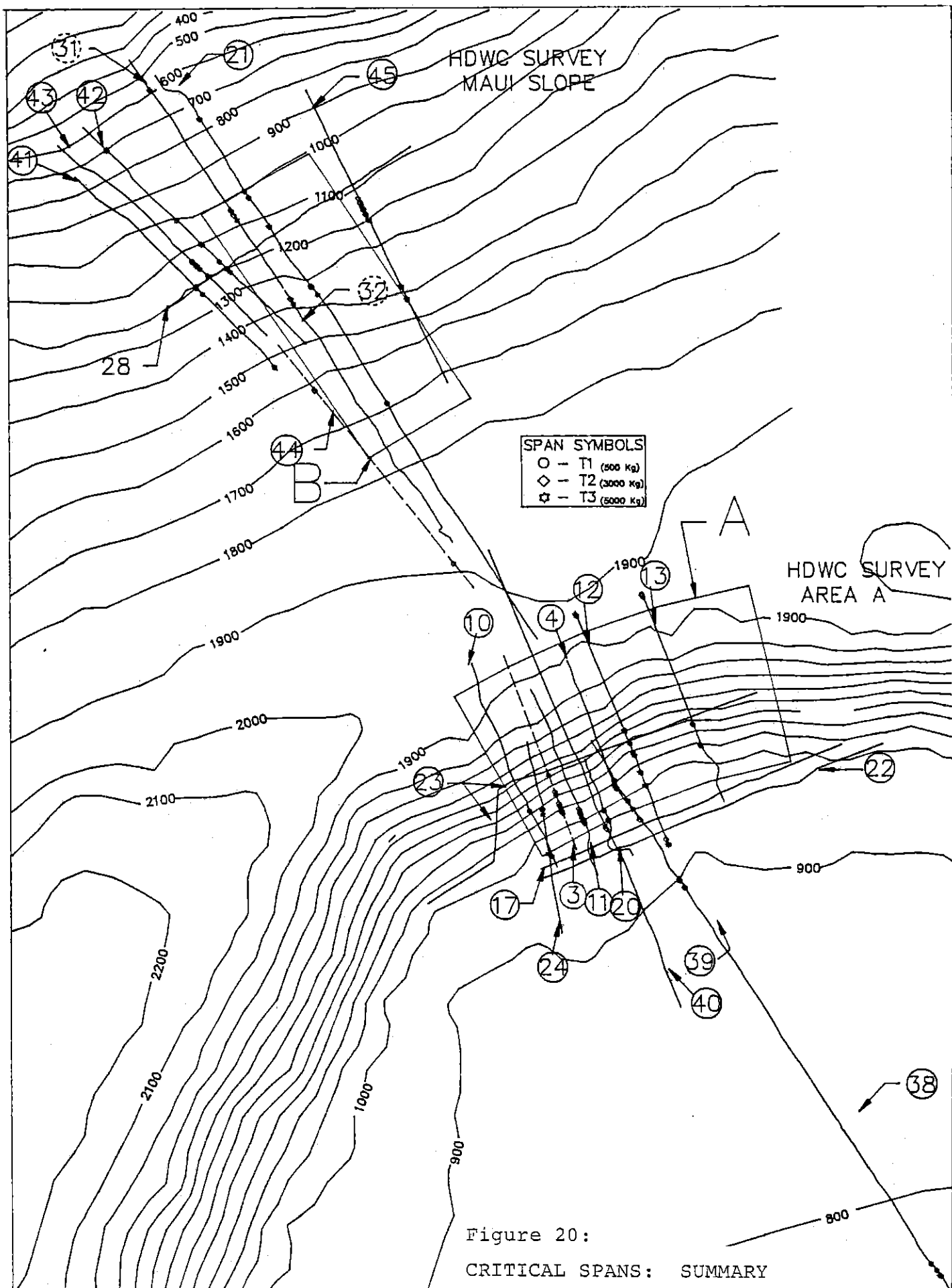
Cable spans were evaluated under three different tensions (500kg, 3000kg, 5000kg) in order to determine the tension least likely to result in unacceptable spans over the surveyed profiles. The critical span length increases greatly with tension (19.6 m at 500 kg; 37.7 m at 3000 kg; and 48.2 m at 5000 kg) but the higher tension cables also result in larger spans on the bottom; it was unclear whether the higher or lower tensions would result in fewer unacceptable spans. It is clear, from the results tabulated in Figure 21, that 500 kg tension yields the fewest number of critical spans for a given profile. In general, the lower the tension, the fewer the critical spans. There are a few exceptions where the larger tension is better, for example, between two high rocks 40 m apart; all tensions result in a 40 m span, but the 5000 kg cable span is not a critical one. These exceptions can be clearly seen in the profiles which are provided in the appendix.

While evaluating the profile data produced by the BRS survey, it was not certain whether bend radius (leading to static cable











## SUMMARY OF CRITICAL CABLE POINTS, SPANS AND BEND RADII

1/31/86  
DE-SPIKED DATA

## ALENUIHAHA CHANNEL SURVEY CRUISE I

TRACK	TENS KG	CRIT SPAN m	# OF CRITICAL POINTS			SPAN LENGTHS (METERS)						
			SPANS	RADII w/o SPANS	per km	15-20	20-25	25-30	30-35	35-40	40-50	50-100
10	500	19.6	0	0	0.00	1	0	0	0	0	0	0
10	3000	37.7	0	0	0.00	16	6	5	6	0	0	0
10	5000	48.2	2	0	0.40	20	10	10	10	2	3	1
11	500	19.6	1	0	0.12	5	1	0	0	0	0	0
11	3000	37.7	5	0	0.62	9	2	1	0	1	5	0
11	5000	48.2	3	0	0.37	21	11	3	1	1	2	3
20	500	19.6	0	0	0.00	3	0	0	0	0	0	0
20	3000	37.7	1	0	0.37	10	6	1	1	1	1	0
20	5000	48.2	2	0	0.73	10	10	7	1	2	0	2
21	500	19.6	1	0	0.07	7	1	0	0	0	0	0
21	3000	37.7	5	0	0.34	27	20	7	3	1	5	0
21	5000	48.2	7	0	0.48	38	25	16	12	5	6	5
24	500	19.6	1	0	0.22	18	1	0	0	0	0	0
24	3000	37.7	1	0	0.22	45	20	7	13	3	0	1
24	5000	48.2	3	0	0.67	36	25	13	13	9	1	3
35	500	19.6	0	0	0.00	0	0	0	0	0	0	0
35	3000	37.7	1	0	0.18	3	2	1	5	1	0	1
35	5000	48.2	2	0	0.35	5	2	1	0	4	3	2
36	500	19.6	0	0	0.00	0	0	0	0	0	0	0
36	3000	37.7	0	0	0.00	1	1	0	1	0	0	0
36	5000	48.2	0	0	0.00	7	1	0	1	0	0	0
37	500	19.6	0	0	0.00	0	0	0	0	0	0	0
37	3000	37.7	1	0	0.22	13	4	2	0	0	1	0
37	5000	48.2	3	0	0.67	29	10	3	0	0	1	3
38	500	19.6	0	0	0.00	0	0	0	0	0	0	0
38	3000	37.7	0	0	0.00	3	0	0	0	0	0	0
38	5000	48.2	0	0	0.00	10	6	0	0	0	0	0
39	500	19.6	1	0	0.17	8	1	0	0	0	0	0
39	3000	37.7	4	0	0.67	32	13	8	5	4	1	2
39	5000	48.2	4	0	0.67	34	19	3	12	4	8	4
40	500	19.6	0	0	0.00	5	0	0	0	0	0	0
40	3000	37.7	1	0	0.09	21	8	5	4	3	0	0
40	5000	48.2	1	0	0.09	38	13	11	7	4	4	1
41	500	19.6	1	0	0.16	11	0	0	0	0	0	0
41	3000	37.7	5	0	0.81	20	8	8	2	4	0	0
41	5000	48.2	3	0	0.49	12	10	7	2	2	3	3
42	500	19.6	2	0	0.30	4	2	0	0	0	0	0
42	3000	37.7	4	0	0.61	10	10	4	3	2	1	3
42	5000	48.2	4	1?	0.61	8	10	10	2	2	5	3
43	500	19.6	2	0	0.30	2	2	0	0	0	0	0
43	3000	37.7	4	0	0.61	13	10	3	3	2	1	4
43	5000	48.2	4	0	0.61	10	10	10	2	1	4	4
45	500	19.6	2	0	0.28	13	1	1	0	0	0	0
45	3000	37.7	7	0	0.97	24	15	5	4	2	6	1
45	5000	48.2	6	0	0.84	16	19	5	2	2	7	5

Figure 21.

fatigue) was a lesser or greater problem than critical spans (associated with dynamic cable fatigue). The computer analysis was run at various tensions and on nearly all survey tracks to determine whether cable bend radius is a critical problem. The results of the analysis is shown in tabular form in Figure 21. As can be seen, critical bend radii almost always occur in conjunction with critical spans. There are one or two instances where unassociated bend radii occur, and the spans in these instances are very nearly critical. This is important relative to bottom roughness evaluation since spans are easier to evaluate than are bend radii. In the appendix is a discussion of bend radii, and the method of computation.

### 3.3 ROUGHNESS OBSERVATIONS, SPECIFIC AREAS

#### 3.3.1 Kohala Slope, Area A

Figure 22 is a plan view of the survey tracks and critical spans on the Kohala slope. To complement this plan view of the Kohala slope, Appendix A shows the detailed profiles along these tracks.

Most of the roughness on the Kohala Slope occurs between 950 m and 1300 m. The area between 1300 m to 1920 m is smooth for almost every track and with a relative roughness which is uniform and less than 0.5 m as observed in the profiles. In contrast, every track in the 1000 m range showed significant bottom roughness with outcroppings from 3 to 10 m. Because of the difficulty at the top of the Kohala Slope, 3 tracks were made along the upper edge, parallel to the slope contours (Tracks 17, 22 and 23). These cross tracks clearly illustrate several lava flows on the eastern side of the upper Area A. Tracks 15 and 39 also traverse these lava flows illustrating features up to 15 m high.

Track 23 was run parallel to the contours at about the 1400 m contour. This track graphically illustrates (Figure 23) that the Kohala Slope has a series of ridges and valleys that run perpendicular to the contours and that it is not a perfectly uniform slope. The detailed boxed views from track 23 can be found in appendix A.

The final run made in Area A was Track 40, illustrated in Figures 24 and 25, which is on the western side. These profile views are drawn to true scale and the rough areas that result in cable spans, view A, are shown to a larger scale in figure 25. Note that the cable spans are illustrated for each of the three tensions.

Track 40 was an attempt to cross the apparently clear areas shown by the SeaMARC data and to avoid the lava flows which were observed to the east. A 20 m escarpment was discovered above the 900 m mark; this is probably the edge of the basin-like structure observed in the SeaMARC data directly above and slightly to the east of Area A. No critical spans are predicted by analysis for this somewhat gradual escarpment. Track 40 also shows significant features at the top of the Kohala Slope, resulting in a single critical span at the two higher tensions (see Figure 25). Also evident are some milder features between 1600 and 1700 m. The very bottom of Track 40 also shows some roughness of 2-3 m elevation. Neither of the latter features produce critical spans according to analysis.

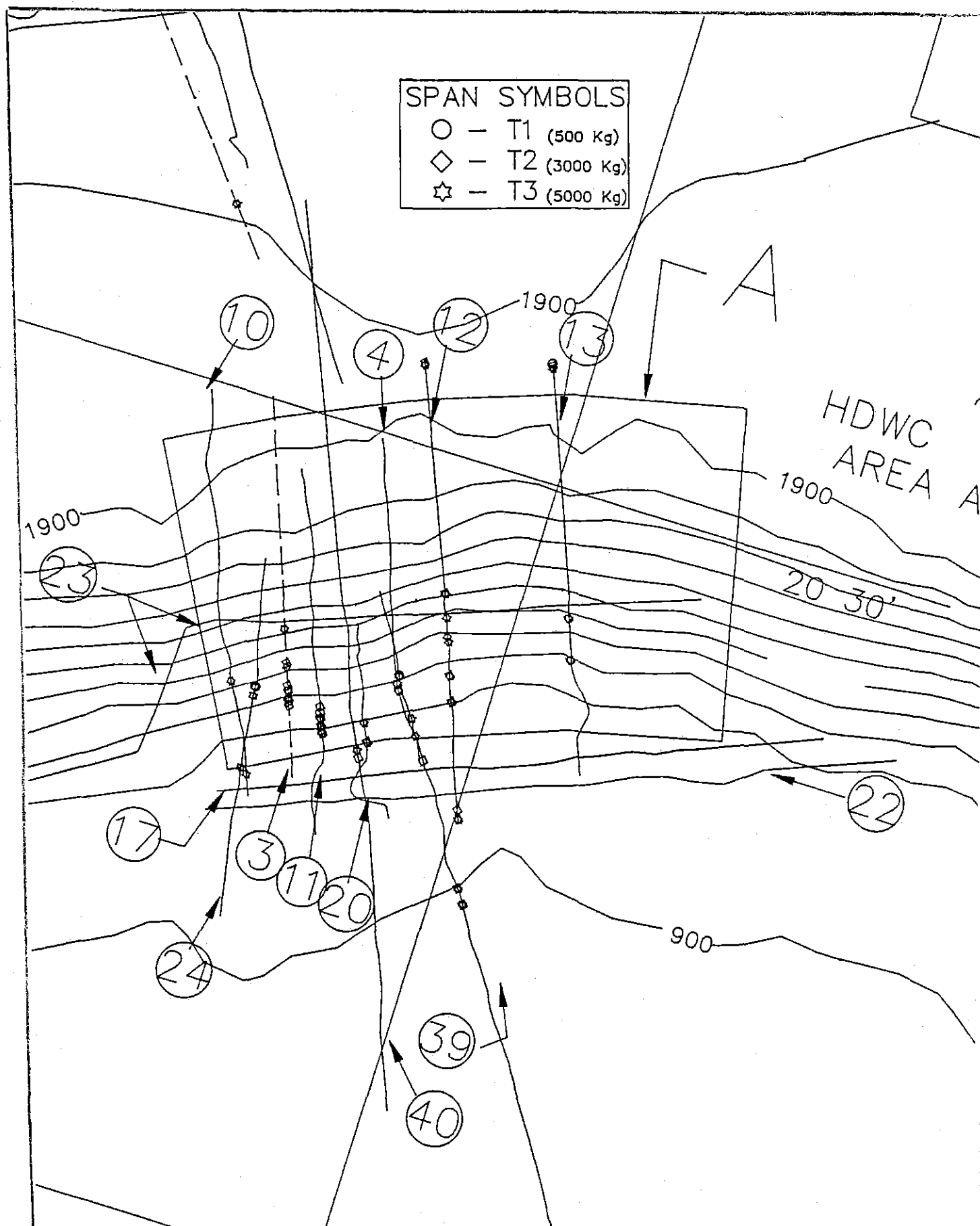


Figure 22

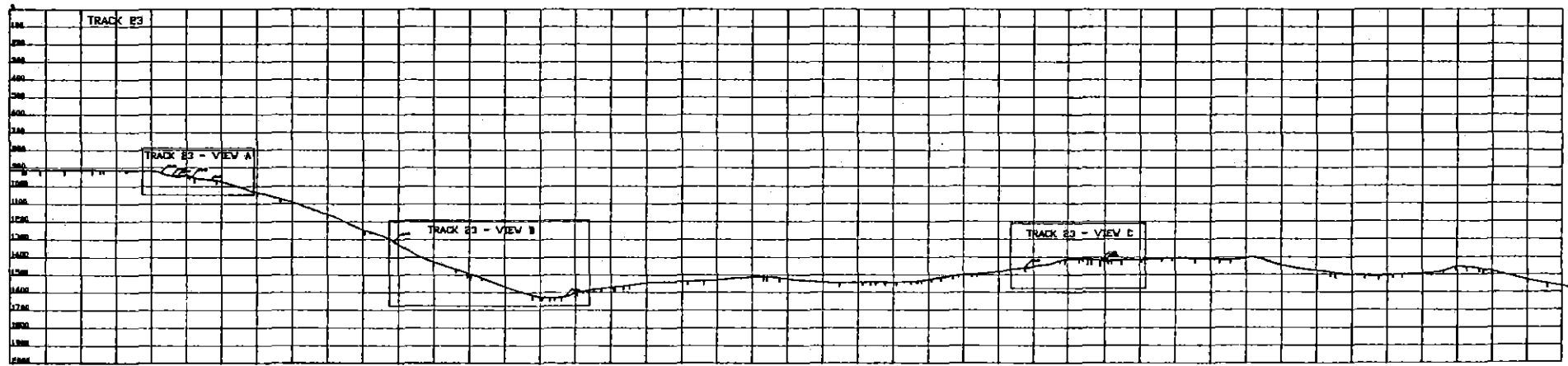
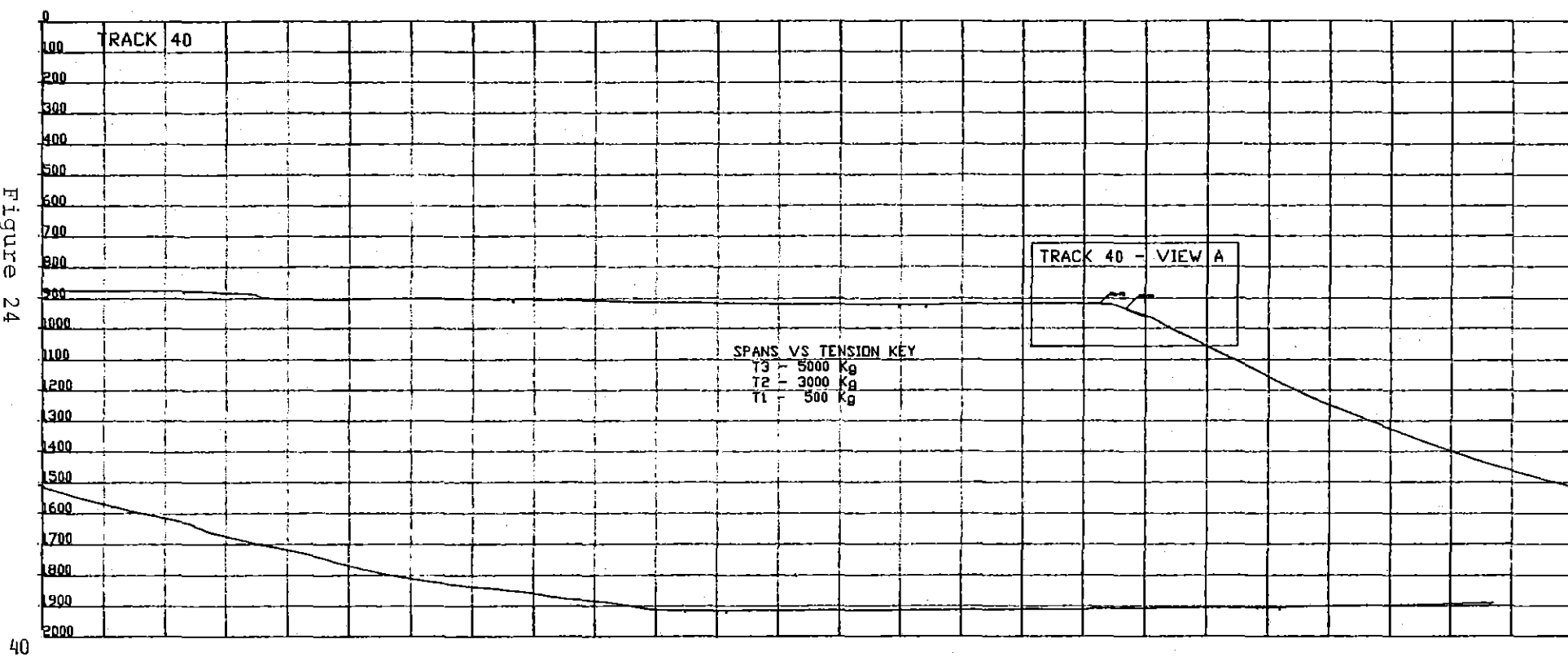


Figure 23

Figure 24

44



40

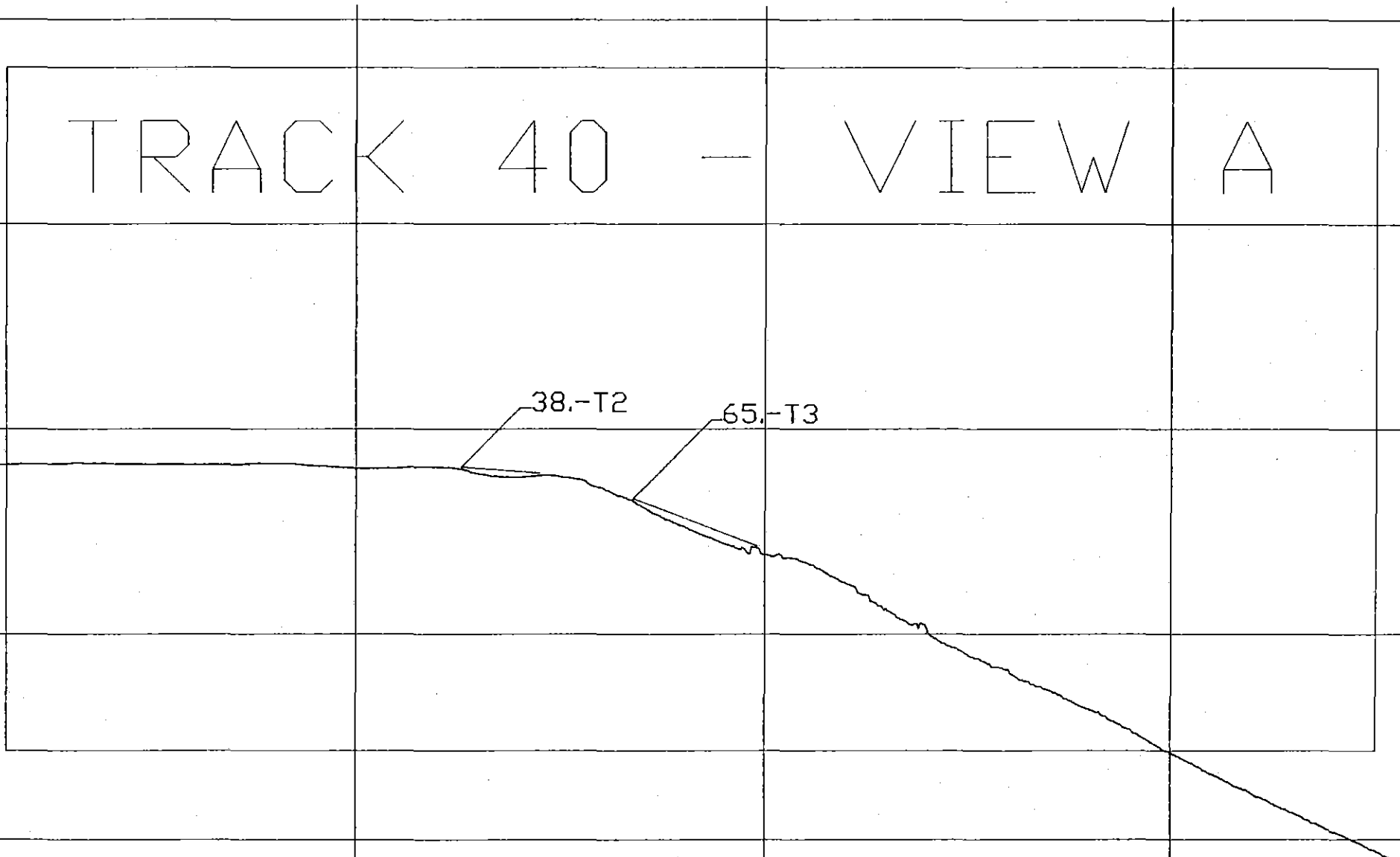
# TRACK 40 - VIEW A

Figure 25  
45

38.-T2

65.-T3

40A



After similar analysis, Track 10 also emerges as a relatively smooth track (see Figures 26, 27). The only critical spans evident arose at a tension of 5000 kg. Analysis at 3000 kg shows no critical spans or bend radii. The only observable characteristic features are two moderate undulations, approximately 50 m long and 5 m deep, which produce critical spans at the 5000 kg tension. The relative smoothness of track 10 is somewhat corroborated by Track 24 (see Appendix), which was nearly parallel to, and following Track 10, although beginning and ending at shallower depths. Track 24 shows two similar undulations as Track 10, at approximately the same depth. Additionally, however, Track 10 shows the emergence of a much rougher escarpment which correlates well with further easterly tracks of increasing roughness.

A clear, wide and obviously smooth path has not been found through the Kohala Slope region. The primary areas of difficulty will be between 850 m and 1100 m depth. For the deeper regions, there appear to be many acceptable cable paths. In the region between 950 and 1000 m there is a great deal of difference in roughness in most tracks. In the shallower regions above the steep slope, however, there is a large lava flow to the east and this will probably narrow the search for a final cable path to the general region of west of, and including Track 40. Although two potential paths have been indicated, there is no assurance that either path is sufficiently wide to insure adequate cable placement.

### 3.3.2 Channel Bottom

The channel bottom, region C2, is fairly smooth and does not have any major features but it is not smooth sediment as previously anticipated. The ends of Tracks 21 (Figure 29) and 40 (Figure 24) both show rocky areas with 2-3 m elevation, sufficiently uniform and without enough elevation to cause unacceptable spans and bend radii. All the tracks on the Maui side at the 1800 m depth range show relatively uniform ripples, perhaps sand waves, of approximately 4 m elevation from trough to peak; these are not significant to the cable.

### 3.3.3 Maui Slope

The Maui slope was the most complex area to characterize during the cruise. There are large features distributed over the entire slope and it was difficult to determine any particular pattern. Figures 28-37 illustrate the bottom features seen in the Maui tracks. Very large escarpments ranging from 20 m to 150 m were observed at a variety of locations but they did not align themselves along any particular contour. Figure 28 is a summary of the critical spans predicted by analysis of the Maui slope tracks.



Figure 26

47

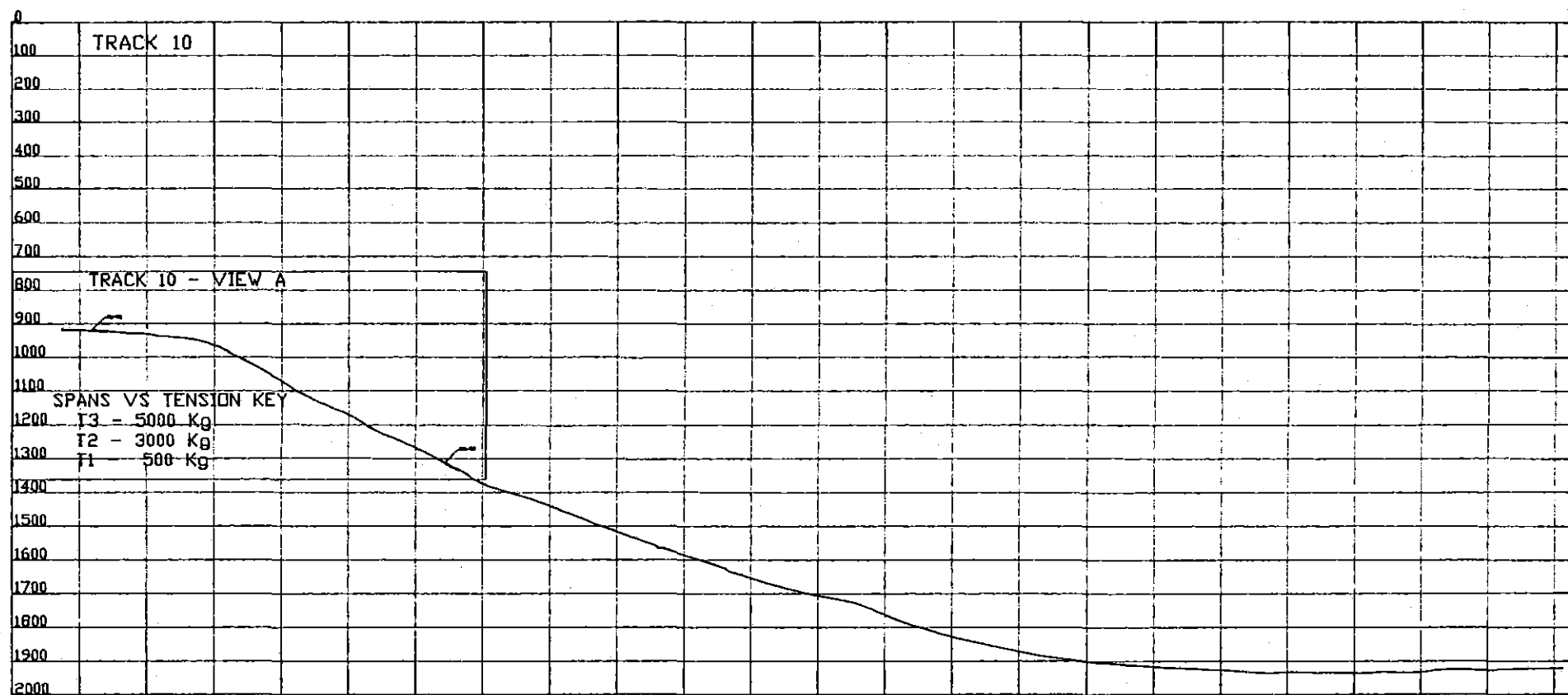
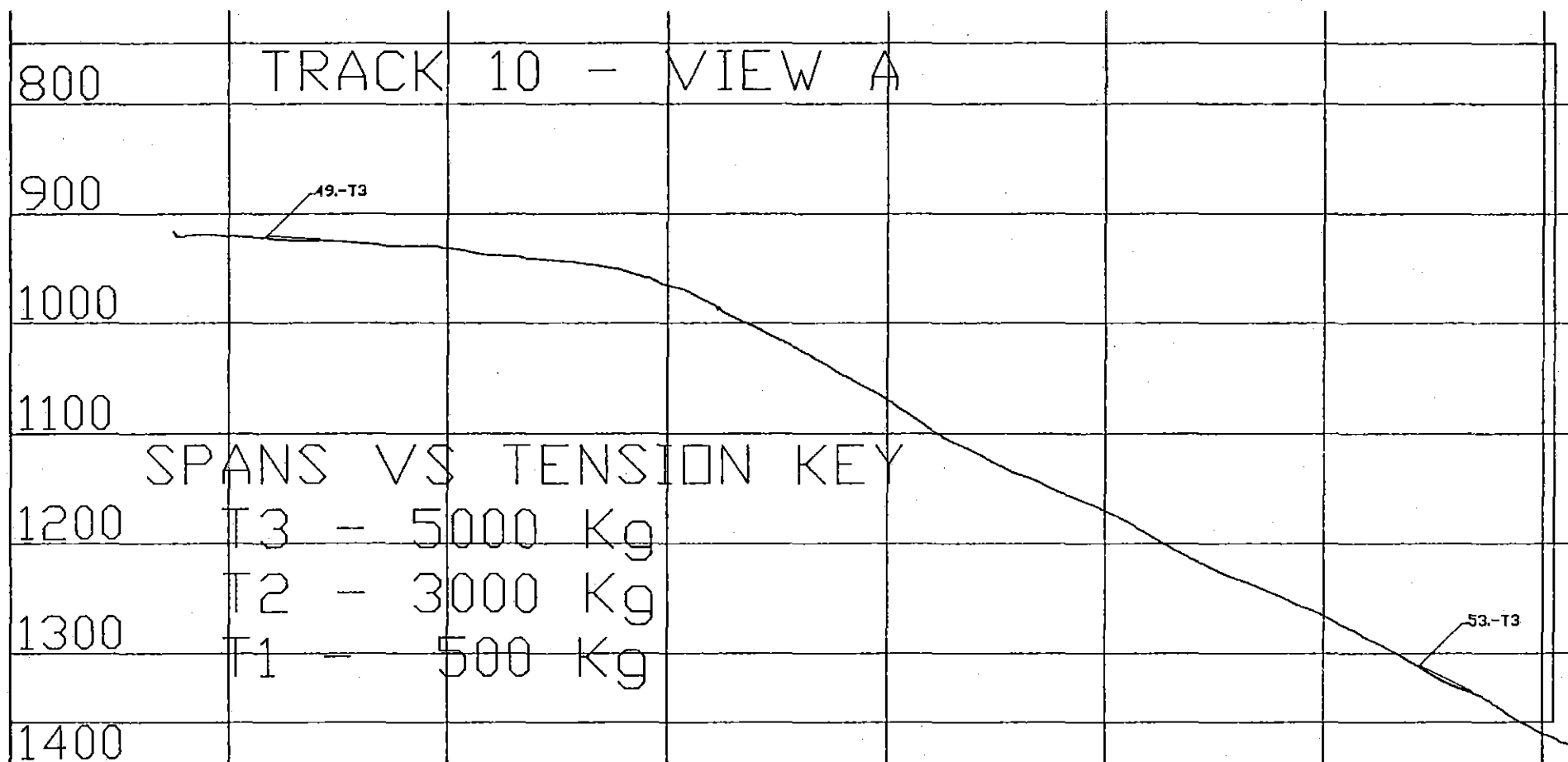


Figure 27  
48



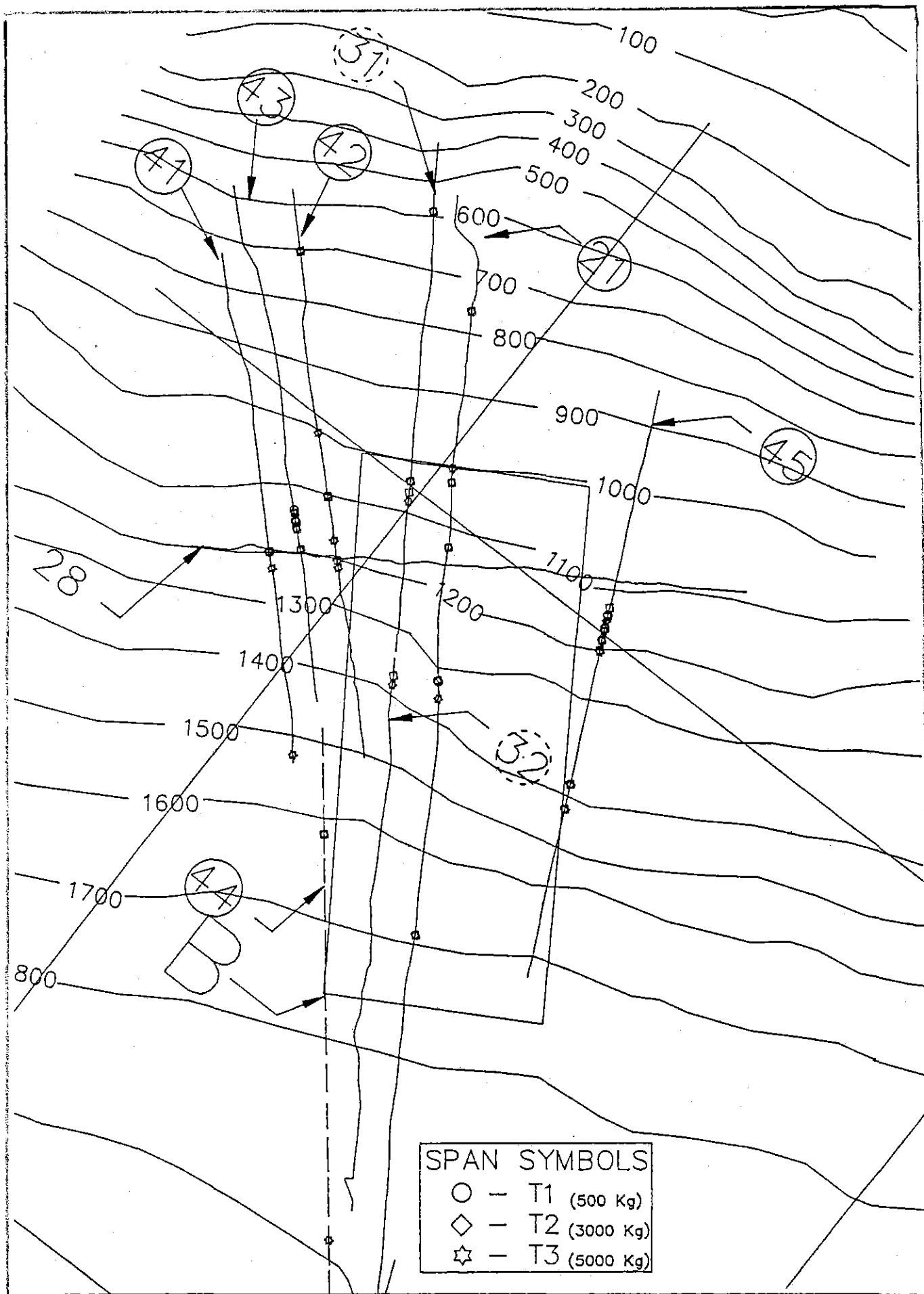
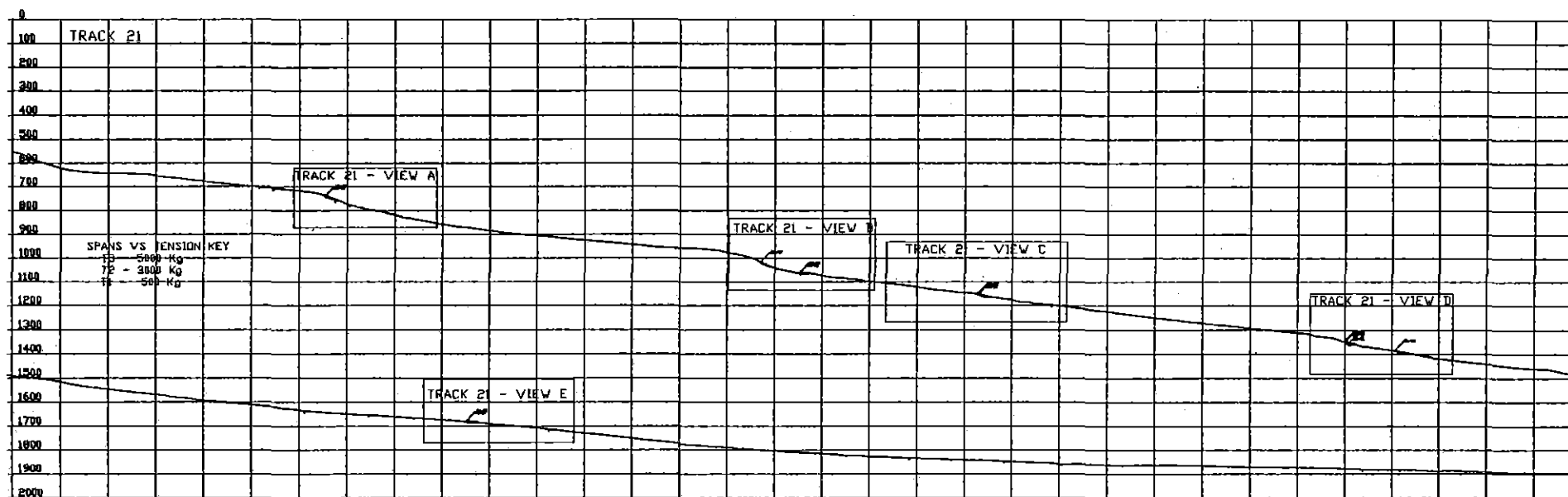


Figure 28

Figure 29



# TRACK 21 — VIEW A

55.-T3  
42.-T2

Figure 30  
51

# TRACK 21 - VIEW B

58.-T3

49.-T3  
41.-T2

Figure 31  
52

# TRACK 21 - VIEW C

65.-T3  
49.-T2

Figure 32  
53

# TRACK 21 - VIEW D

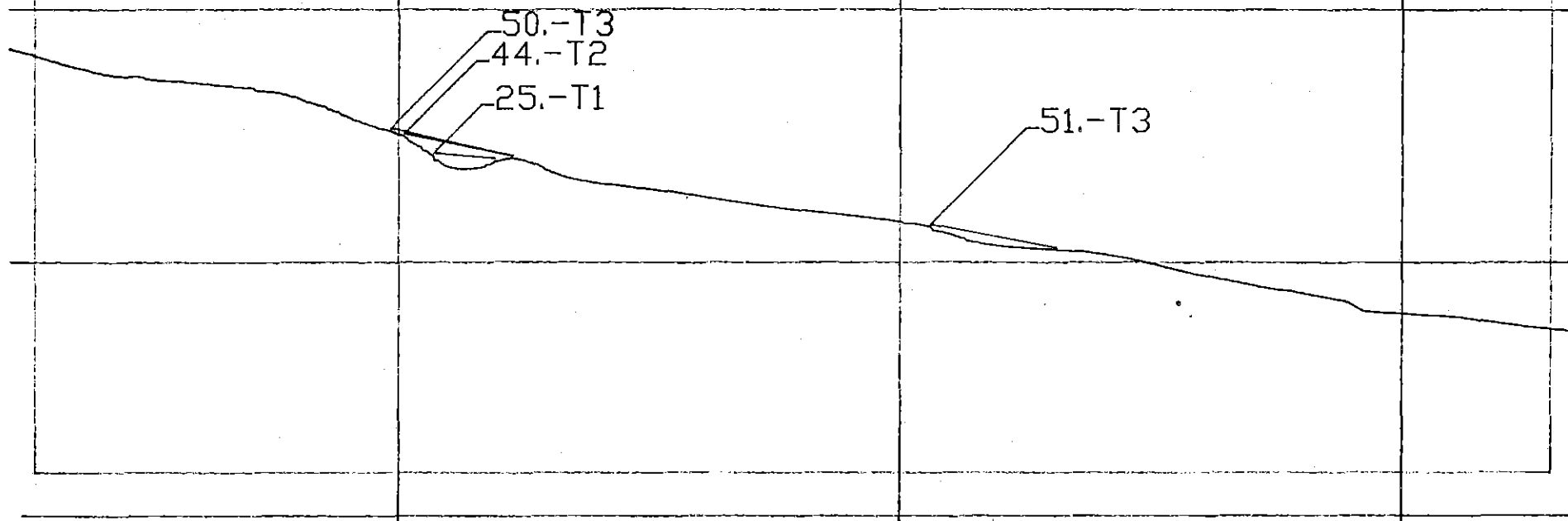


Figure 33

54



# TRACK 21 - VIEW E

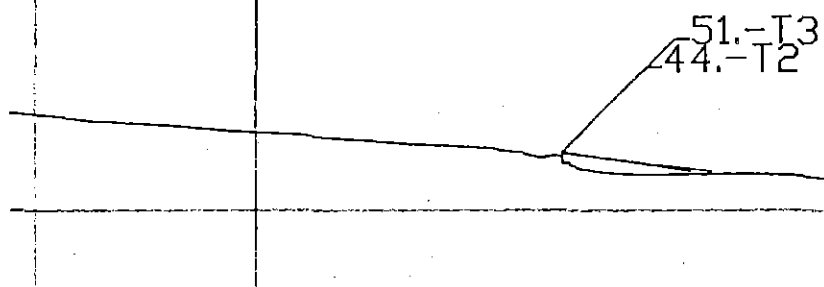
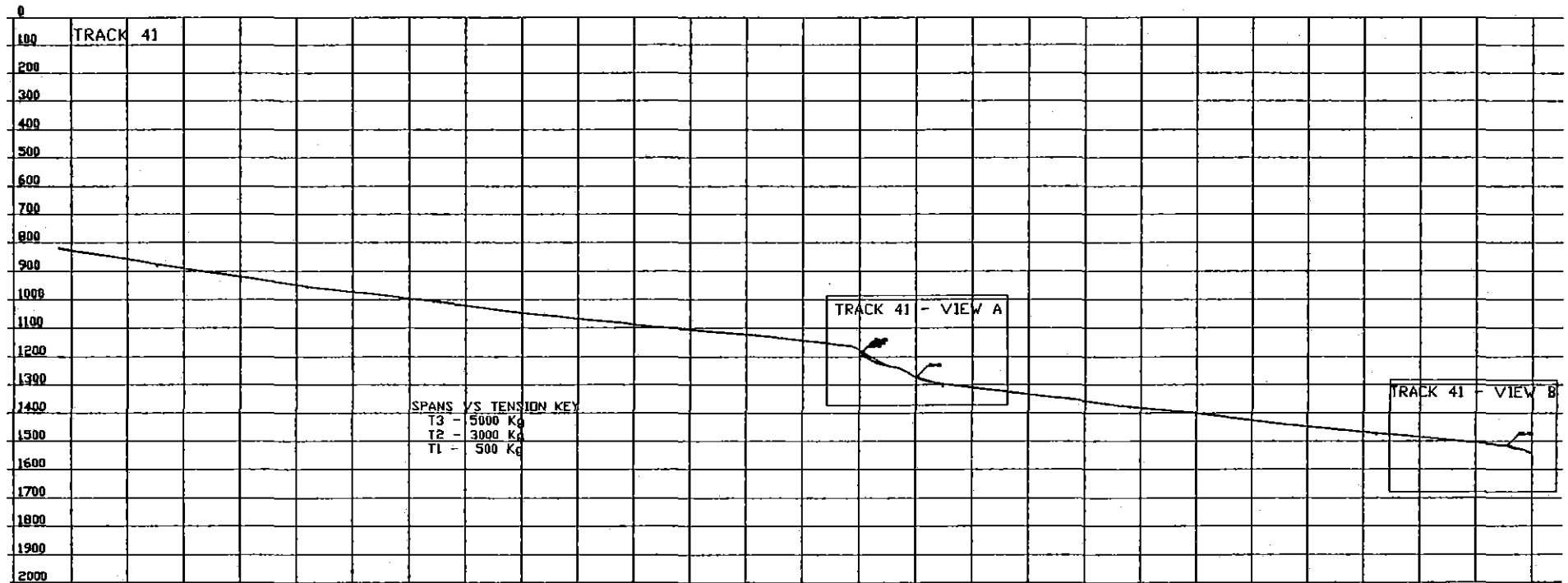


Figure 34  
55

Figure 35

56

41



# TRACK 41 - VIEW A

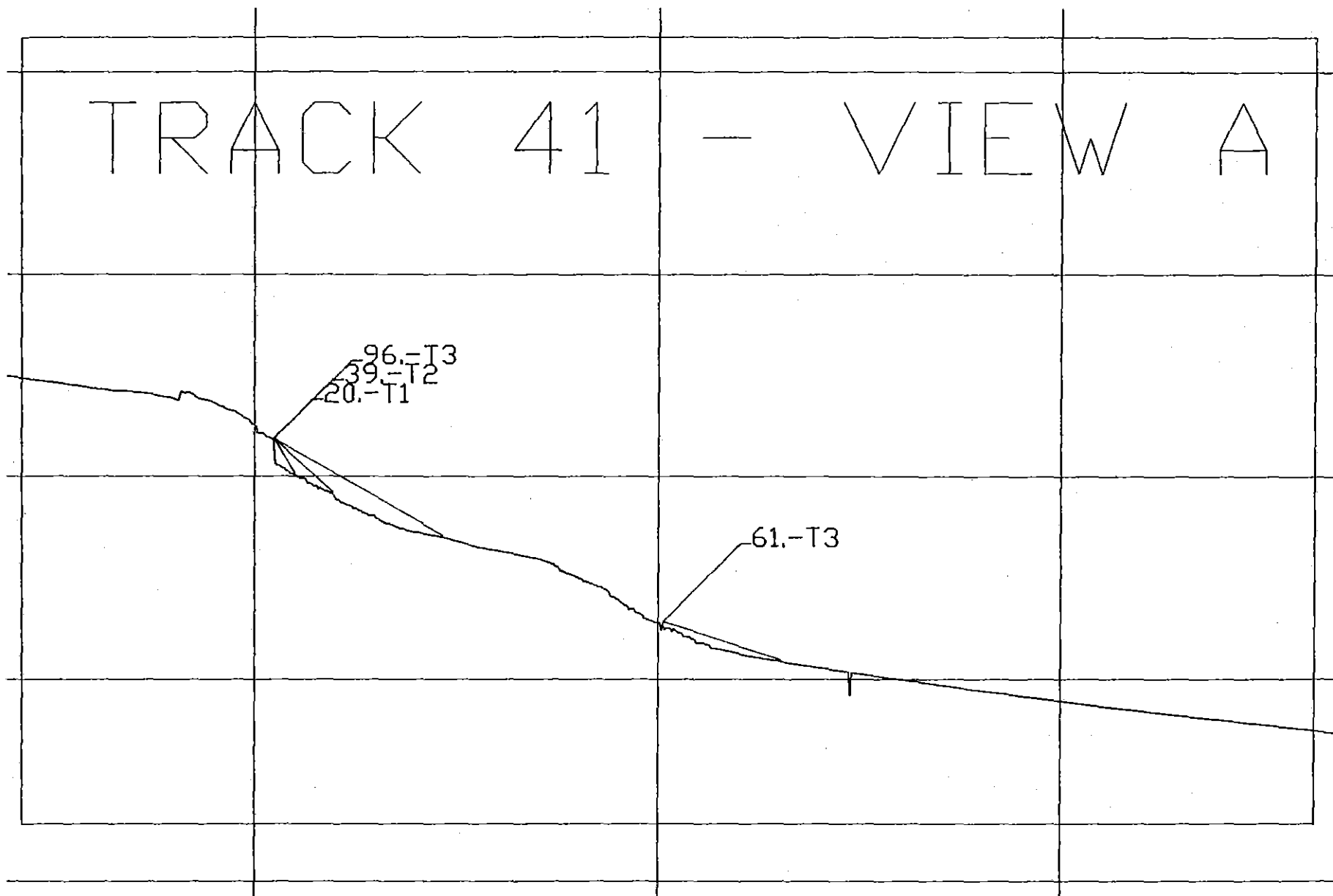


Figure 36  
57

# TRACK 41 - VIEW B

Figure 37

58

53.-T3

41B

The region of greatest roughness appears to be at depths of between 1000 and 1400 meters, with considerable roughness particularly in the region of Track 45.

The first Maui tracks that were run, number 21 and number 31 illustrate that the slope is relatively smooth above 1000 m and that there are large, smooth areas mixed with areas of significant roughness and escarpments. At 1000 m depth, both Tracks 31 and 21 illustrate a large sloping escarpment, perhaps the front of a lava flow, that is 60 to 100 m high overall. These two tracks also show a smaller escarpment between 15 and 40 m high at 1300 m depth and another level of roughness at 1500 m. All these regions are separated by smooth areas.

Figures 29-34 illustrate Track 21 with associated critical spans as predicted by analysis. At all tensions, there are unacceptable spans and quite probably some unacceptable bend radii. The only steep escarpments are on the order of 10 to 15 m high. There are however, a number of other features of less severity which are sufficiently rough to produce critical spans at all tensions. Track 31 (see Appendix), which neighbors Track 21, could not be analyzed due to excessive noise in the raw data, which could not be filtered without altering the quality of the data.

Several cross runs were made, Tracks 28, 29 and 30, (also noisy data, see Appendix) in the region of most significant roughness between 1000 m and 1400 m depth. These tracks showed that the eastern portion of Area B is quite smooth. Prompted by this data, Track 45 was run on the western slope only to find very large escarpments at 1200 m and at 1500 m.

The SeaMARC data showed a potential path in the regions of Tracks 41, 42 and 43. These tracks, however, show significant roughness (10 to 15 m) and escarpments in the region between 1000 and 1300 m. Of these, Track 41 (Figures 35-37) seems to be the smoothest with only one critical span at a 3000 kg tension. This obstacle, however, is a rather steep escarpment appearing at 1200 m depth.

As on the Kohala Slope, no obvious path was found on the Maui side. The better paths are most likely in the vicinity of Tracks 21 and 41. The most difficult region for finding an acceptable path will probably be in the region between 1000 m and 1400 m in depth. Above and below this range, there is considerably more clear space and a higher probability that an acceptable path can be found.

#### 3.3.4 Shallow Kohala Slope, Area C3

An extended series of tows were made, (Tracks 35 through 38) in the shallow region of the Alenuihaha Channel on the Hawaii side (Figure 38). In other shallow regions on the island of Hawaii old coral reef structures create significant underwater obstacles. For this particular series of tracks, the vast majority of the bottom was fairly smooth. Some regions of rock outcrops occur between 700 and 800 m depth (Track 37) and between 300 and 400 m (Track 35). Most of these obstacles are felt to be isolated ones and can probably be avoided by taking parallel tracks. In this region there is a wide range of maneuverability possible since the channel saddle no longer restricts the route.

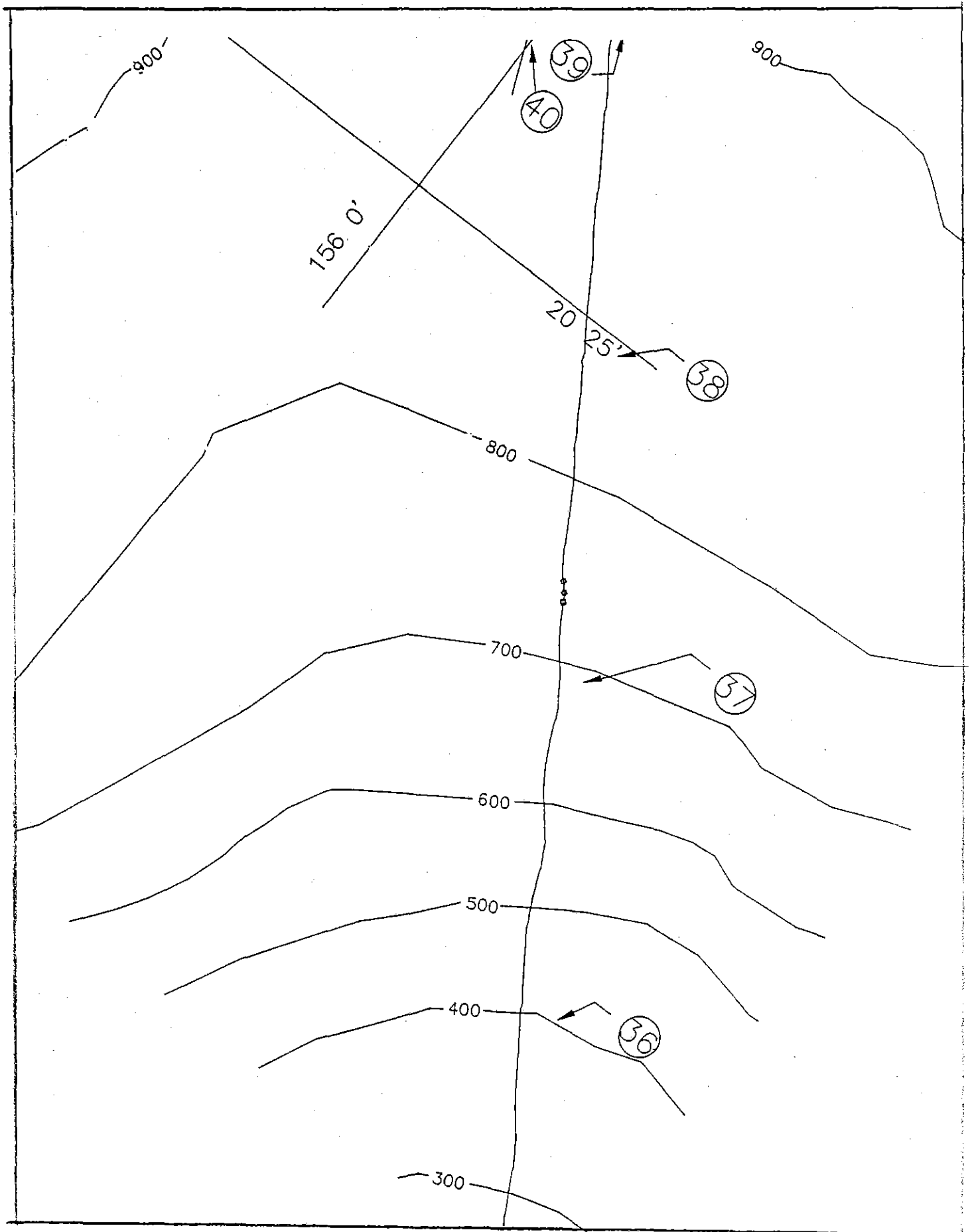


Figure 38

### 3.4 SIDE SCAN DATA

On the following pages are the side scan plots from the SeaMARC survey, divided into the Maui slope and the Kohala slope. A loose acetate copy of the BRS roughness analysis of the Kohala tracks is attached, for comparison with subsequent side scan results which will be referred to throughout this discussion. The acetate and the side scan illustrations are properly scaled and can be aligned for properly locating the BRS data on the side scan results. An acetate of Maui slope BRS roughness analysis results is also provided to be aligned with the side scan frames.

These plates of plotted side scan results were closely examined for identification of features identified, or not identified, in the BRS mission data. For the most part, correlation between the two systems is quite good. In areas with a great number of critical spans as predicted by the analysis, side scan data shows a high degree of roughness, either as scattered boulder-sized obstacles, or as steep escarpments. Exact correlation is not possible due to the BRS positioning errors, and also due to the data stretching nature of side scan at various sweep angles. The gross features of the areas in concern are, however, easily seen and are used along with the BRS mission data to pinpoint areas in need of further surveying for the second cruise.

The following discussion of the side scan data is best followed by using the attached overlays, which can be used to reference any side scan features to the BRS survey tracks, and subsequently, areas of indicated roughness (critical spans).

#### Kohala Slope Side Scan

##### Plate B

This side scan plate is a view of the top and easterly end of the Kohala slope. The roughest portion of the slope seems to be in the area around and between Tracks 12 and 13. At the top of the slope, along Track 13, there are areas of scattered rocky outcrops. The area along Track 40 looks not quite so rough as Tracks 12 and 13, but remains as an apparently steep, relatively rough sloping path.

##### Plate C

Moderate roughness is evident in the area between Tracks 39 and 40, increasing in an easterly direction on and above the Kohala slope above the 1000 meter level in particular. The lower portion of this plate shows some rough areas as well on the flat plain at 900 meters, but these features seem avoidable, and not quite so distinct as those near the top of the slope.



SeaMARC data

Kohala Slope

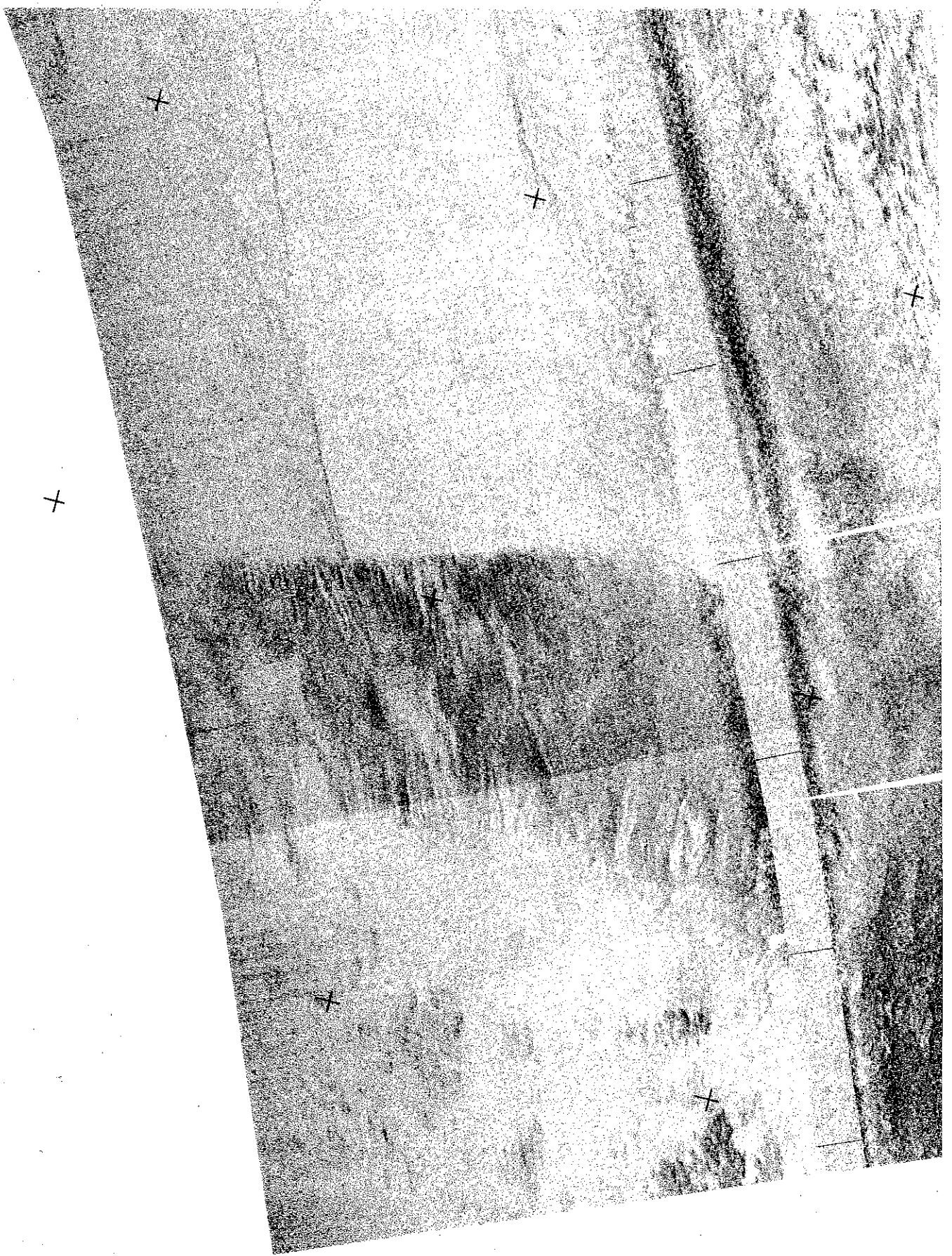
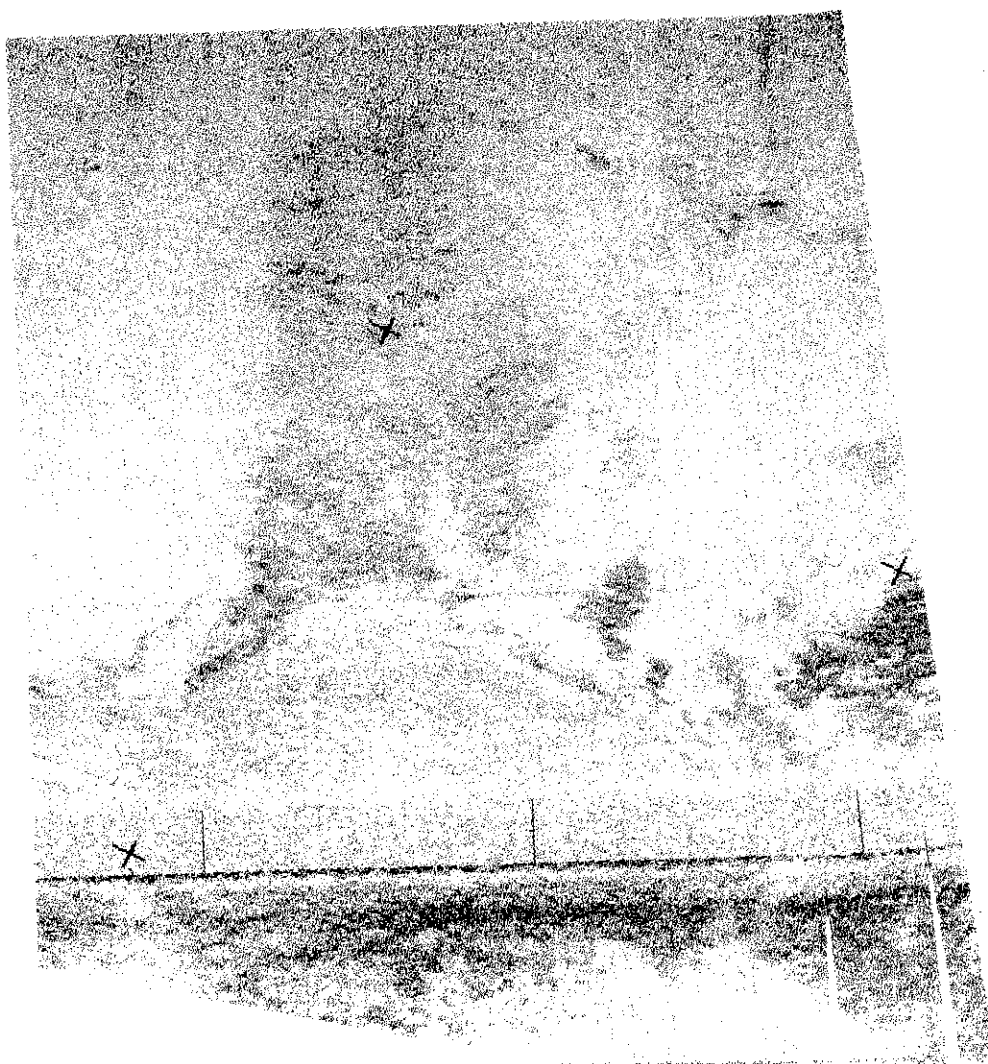
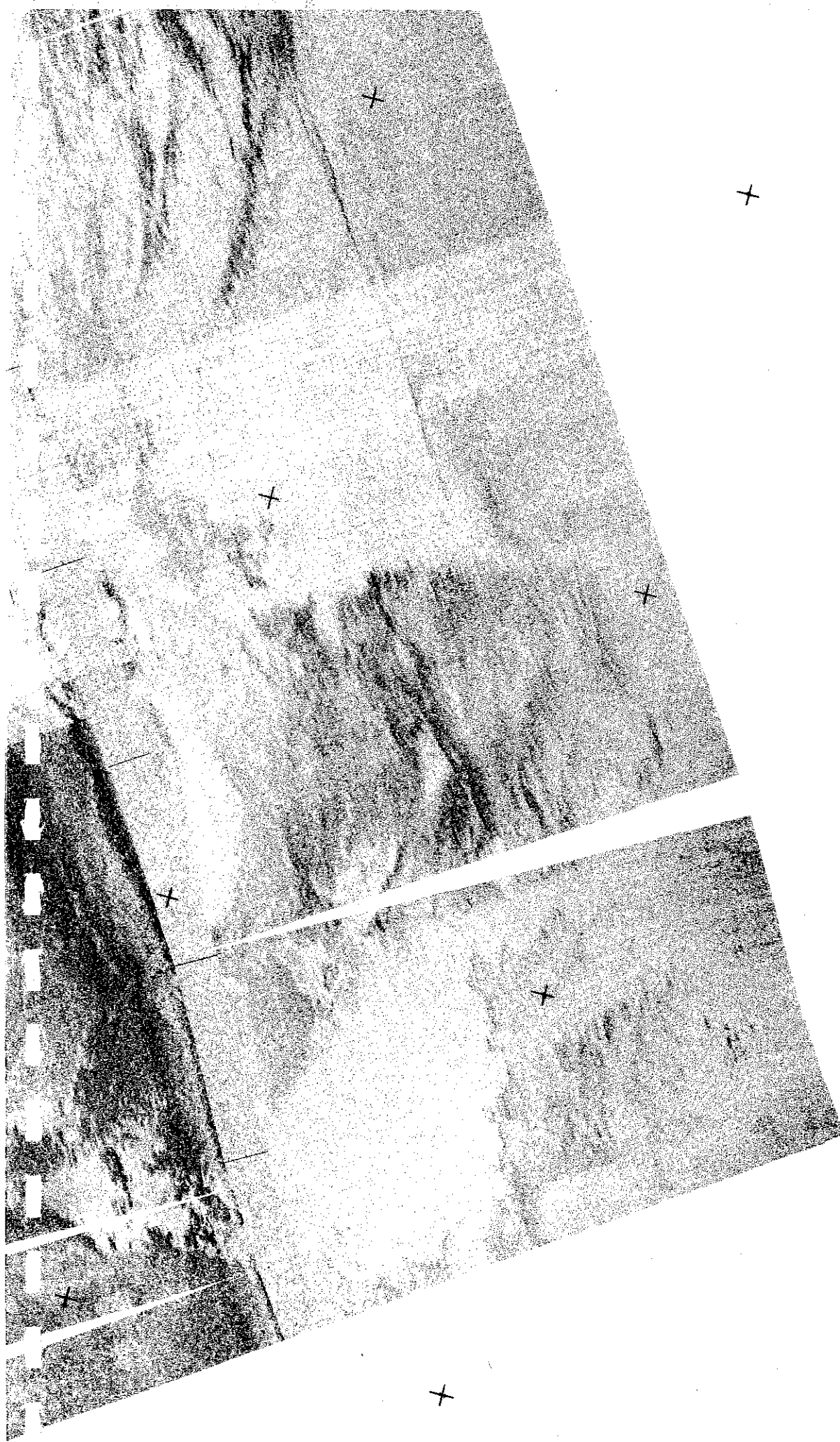


PLATE B

PLATE C





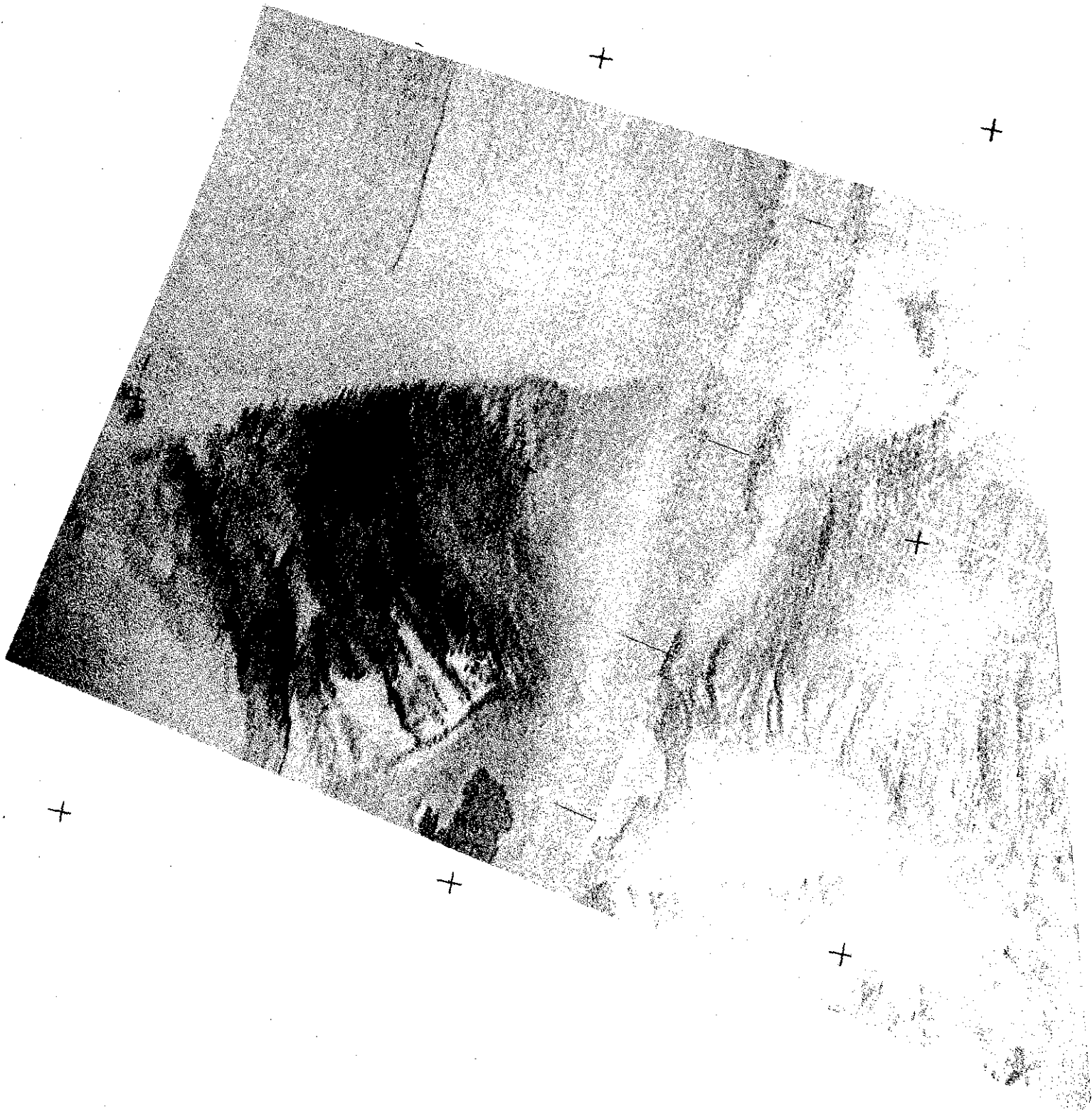


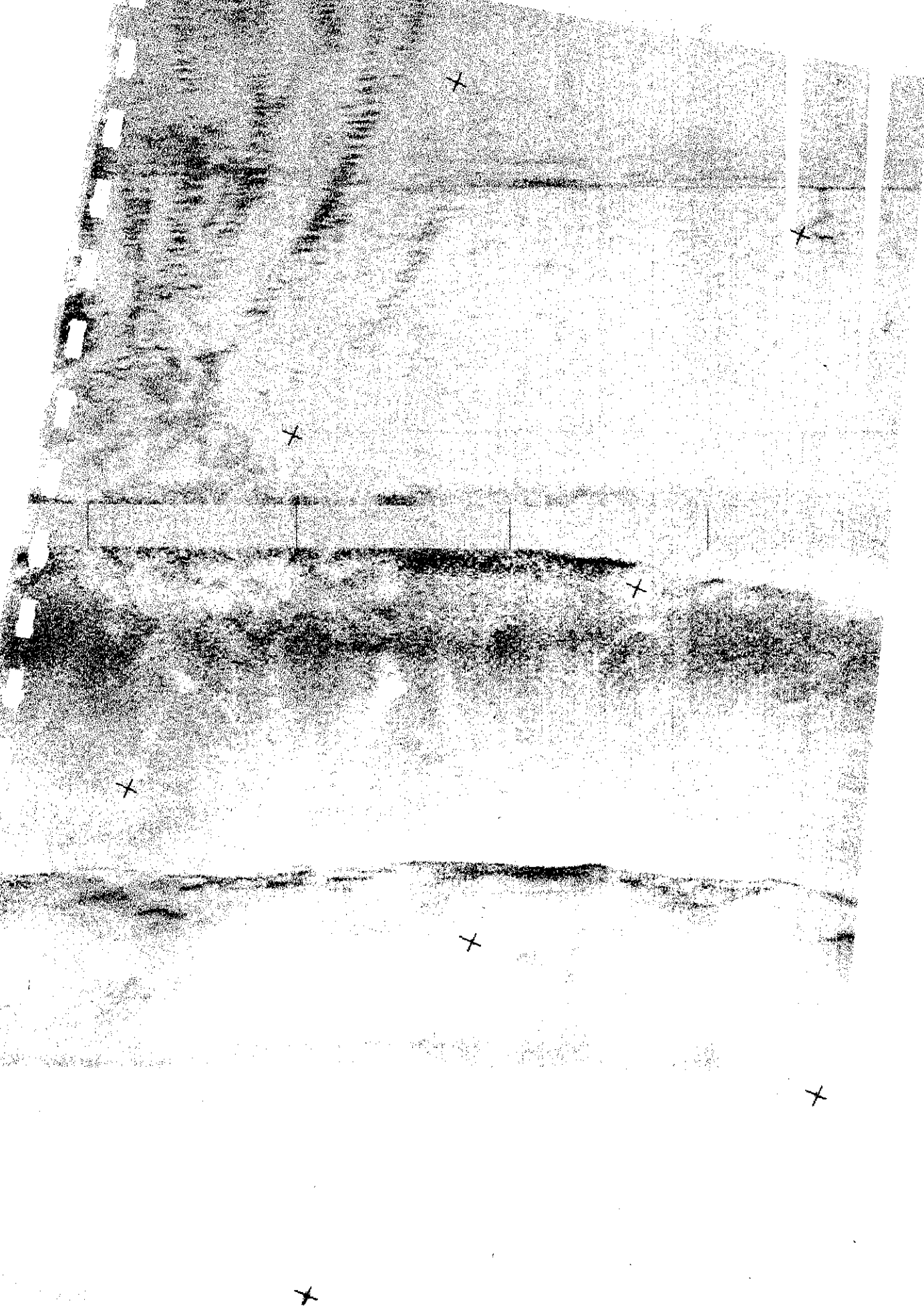
PLATE C







PLATE J





#### Plate D

The center of this plate is a very clear look at the Kohala slope. Debris flows or gullies are evident in a down-slope direction. Scattered rough features are also evident beyond the top of the slope, particularly along Track 39. There is a large smooth open basin, about a kilometer in diameter, at the tops of Tracks 11 and 20. Areas to the west of this, particularly near the top of the slope, appear increasingly rough, more so than to the east. The clearest path seems to be directly in the vicinity of Track 10. This area is very close to being under the path of the towfish, where no further data is available on this particular plate. Areas further to the east of track 13 also look increasingly clear, but this is likely due to diminishing signal return at the fringes of the side scan range.

#### Plate F

This plate provides a nearly perpendicular look at the face of the Kohala slope. Many gullies or debris flows are evident at the top and bottom of the slope. The clear area, denoted previously along Track 10, is now positioned further away, due to elongation of the slope due to the towfish position and viewing angle. The area immediately west, adjacent to the tow path, appears to be extremely rough. This area is likely to be that between Tracks 3 and 12.

#### Plate G

This plate highlights the area to the west of Track 4. This plate again shows a clear area above the slope, along the slope, and below the slope up to the 1900 meter depth. There are some rough features at this 1900 meter mark, which should be investigated. The rest of the path seems clear, with the narrowest region being near the bottom and top edges of the slope, about 500 meters in width.

#### Plate H

This plate provides a different look at the top of the Kohala slope, showing areas of roughness particularly above Tracks 4 and 12. Clear paths, of nearly a kilometer width, show above Tracks 10/11 (basin-like structure) and Track 13 (scattered rocks). This plate again indicates the area above Track 10 as the best path. Although there are some questionably rough areas at the bottom and to the west of this track, they seem to be avoidable, and are possibly due to sand ridges.

#### Plate J

This plate is a cross slope sweep, directly above the Kohala slope. The slope itself is foreshortened due to the angle of the sweep. This swath does however, provide a very good look at the terrain above the slope. This shows evidence of a ridge above the 900 meter contour, which is somewhat weakened in the area of the aforementioned basin above Track 11. Easterly of this, the

ridge seems larger and is also seen in the profiles of Tracks 39 and 40. It should be noted that Track 39 flags critical spans on this ridge. Although at first glance it does not appear to be the same ridge in a plan view, this is due to the angle of the side scan view, which elongates the distance to this feature.

This plate also provides a closer look at the terrain at the bottom of the slope, particularly along the western end. This shows many parallel east-west ridges of about 200 meters in length. These are presumed to be hard sand ridges, which should not present a problem in the cable lay. If necessary, they could be avoided by a controlled cable lay as they are nearly 500 meters apart.

#### Maui Slope Side Scan

##### Plate B

This plate gives a good view of the eastern end of the Maui slope. A great deal of roughness is apparent as rock outcroppings and parallel ridges. This area appears to be the roughest section of the Maui slope. Potential smooth areas lie further to the east, but data in this area is not as plentiful as in the western area.

##### Plate D

This plate was taken on a run perpendicular to the contours of the Maui slope. Many parallel ridges are apparent, with greater scalloped areas to the west as previously seen. The areas directly under the tow path, and to the west, appear to be the smoothest areas. In general, these lie to the east of Track 41. In these areas, there are scattered parallel ridges and outcroppings which may not induce critical spans or bend radii, or at the worst seem avoidable. This appears to be the best potential cable route through the Maui slope, and is worthy of further investigation.

##### Plate E

This plate shows a great deal of moderate roughness levels, scattered over nearly the entire image. The east side appears to be more dense in the areas of roughness. Far to the west, the terrain appears smoother, but it is difficult to reach any conclusions about this area since it is nearly out of the side scan field image. The east side holds much more scattered roughness, although of apparently greater intensity, due to the scalloped out areas potentially yielding escarpments along the edges. Overall, this side scan image portrays the image deduced from the roughness analysis. That is, there are no immediately evident cable paths through this terrain; the best potential seems to lie along the western quarter of the slope, potentially aligning with Track 41 and westerly.

SeaMARC data

Maui Slope

X

X

X

X

X

X

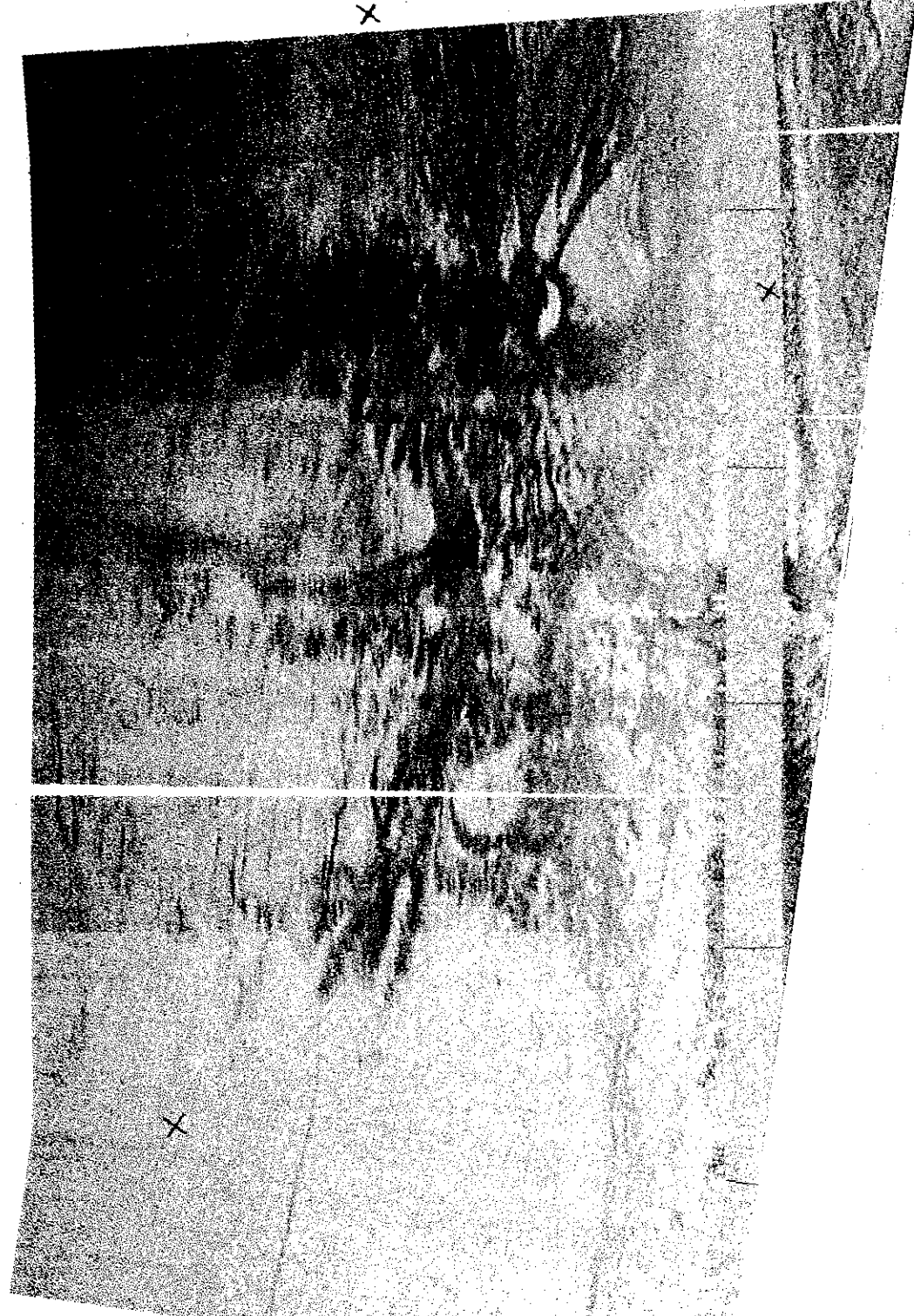
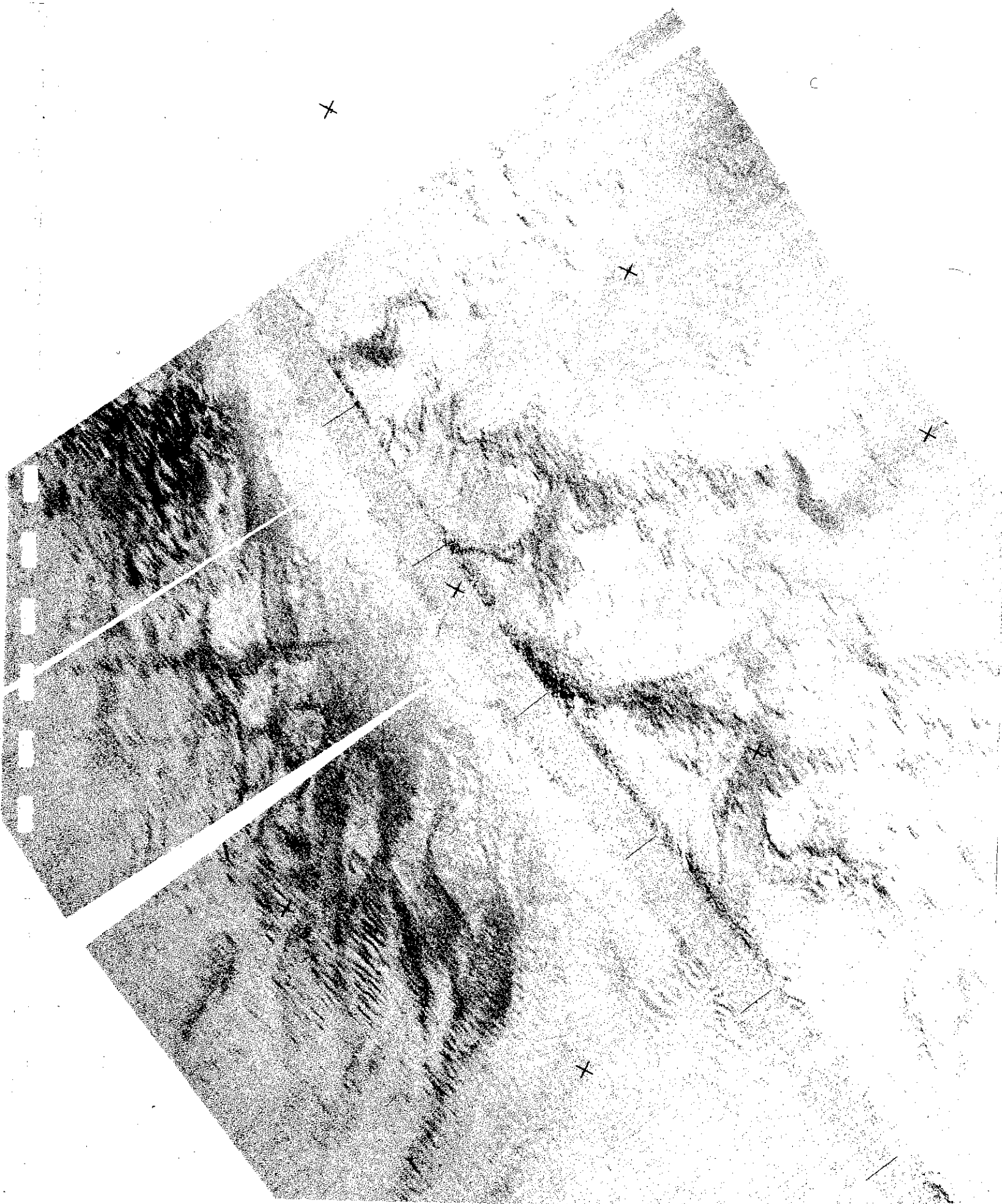


PLATE D





### 3.5 BATHYMETRY OBSERVATIONS

The BRS was located relative to the tow ship, as described previously. The profile data was therefore available in an X, Y, and Z format. The 100 meter contour marks were then determined along each survey profile, and plotted in a plan view for selected profiles. This is shown in Figures 39 and 40, for the Kohala slope area and the Maui slope area respectively. Agreement is seen in a comparison of profile contour marks with NOAA bathymetry on the Maui slope (Figure 40). Most profile contour marks agree within 100 meters of NOAA contour lines. On Track 45, however, contour marks show two major escarpments at the 1100 and 1400 meter levels that do not show up in NOAA contour lines. These escarpments may be localized enough to only show up in the BRS survey, since they do not show up in the nearby Track 21.

The results of the BRS positional corrections can be evaluated by comparing overlapping BRS tracks. Such an evaluation can be made by examining the 100 meter contour marks in the area between tracks 4 and 11 along the Kohala slope (Figure 12). The contour marks generally cluster on the upslope side of the corresponding contour lines, ranging up to 100 meters away, until the slope flattens out. The contour marks of other overlapping tracks agree very well with each other also. This is seen in tracks 20 and 40 which agree to within approximately 50-75 meters, and again in tracks 4 and 39, which agree to within 75-100 meters. The discrepancy between these contour marks is somewhat variable, due to the nature of the correction which is a function of depth and velocity, but it is sufficiently accurate to identify areas of roughness.

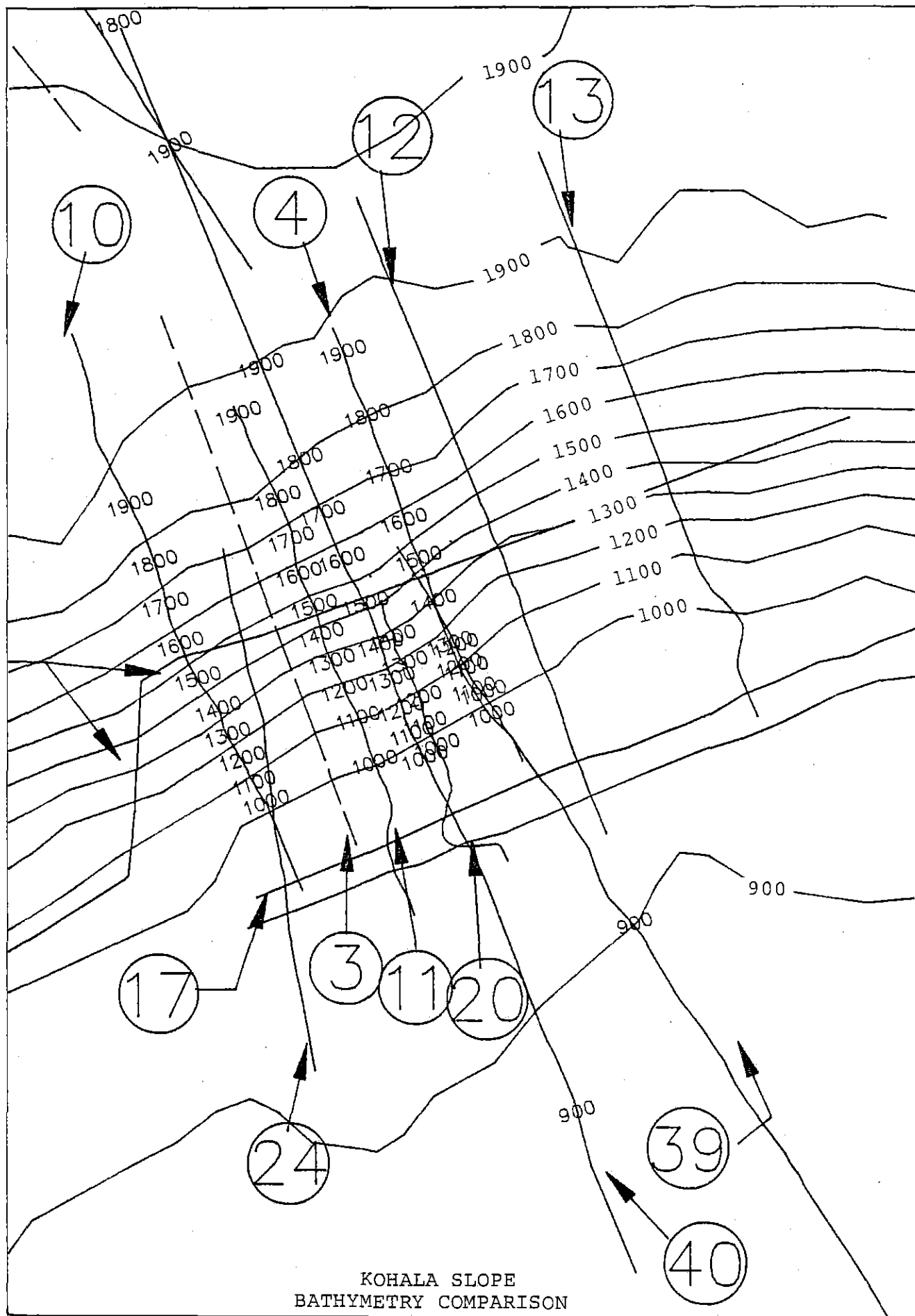


Figure 39



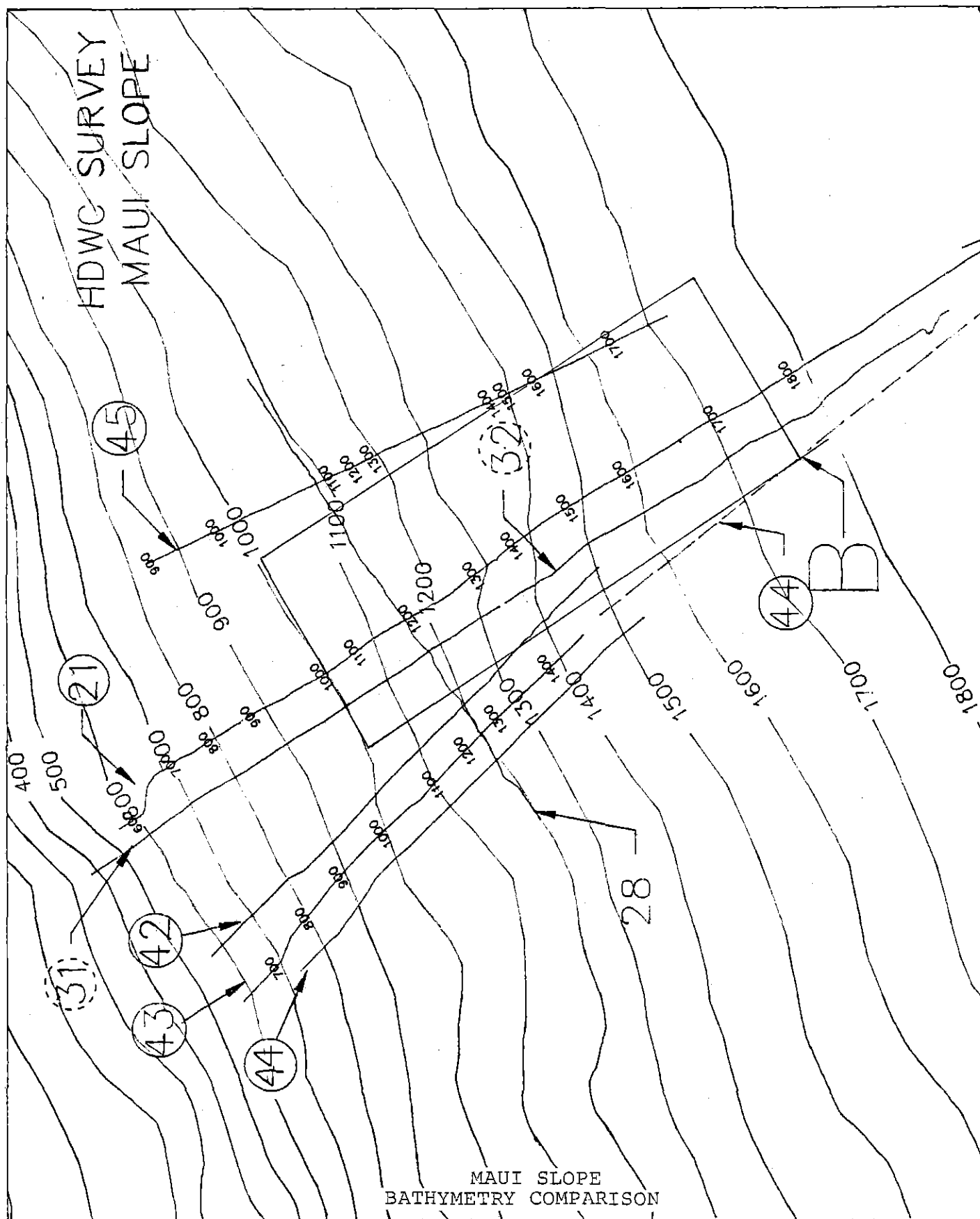


Figure 40

### 3.6 GEOLOGY

The geologic history of the Alenuihaha Channel area starts 80 - 100 million years ago when the ocean crust in this area was formed at the crest of the East Pacific Rise, at a location 20 - 30 degrees south of the present equator. Since then this sea floor has been moved to the northwest by plate tectonic forces. Approximately 700,000 - 1 million years ago the sea floor northwest of the Alenuihaha Channel area crossed the Hawaiian hot spot and the Haleakala Volcano was born.

As Haleakala grew the weight of the new material put on the ocean floor, along with removal of material from below the sea floor needed to produce the volcanism, caused this large edifice to subside. This subsidence most likely was still an ongoing process when the volcano first grew above sea level and thus the original subaerial portions of Haleakala Volcano subsided below sea level as the volcano grew. As Haleakala moved away from the hot spot its major period of shield building volcanism ceased and was followed by erosion of deep valleys on the flanks of the volcano. These valleys, up to a few hundred meters deep, are most evident on the windward side of the volcano from Haiku around the southeast end of the island to Kaupo. Merger of the heads of Kaupo and Keanae valleys formed the large depression at the peak of the volcano that is Haleakala Crater. Approximately 200,000 years ago volcanic activity resumed along the principal rift zones of Haleakala producing the post-erosional Hana Volcanic Series eruptions. The latest of these post-erosional eruptions occurred near the southwest tip of the island in 1790. Large lava flows produced by the post-erosional activity near the summit of the volcano were channeled down Kaupo Valley and may have flowed out to sea and formed some of the undersea scarps discovered on the Maui slope of the Alenuihaha Channel.

As Maui moved away from the Hawaiian hot spot volcanic activity was initiated to the south of Alenuihaha Channel. This produced the island of Hawaii. First to emerge was the Kohala Volcano, which probably first appeared above sea level 500,000 - 700,000 years before present, and more recently the other volcanoes to the south and east. The growth of the Kohala Volcano south of Haleakala produced a saddle between the two mountains that is responsible for the primary topographic shape of the floor of the Alenuihaha Channel.

As the Kohala Volcano and later the other volcanoes on Hawaii grew, the island subsided. This subsidence has submerged the original shoreline of Kohala approximately 1 km below the present

sea level. The effect of putting the mass of the island of Hawaii on the ocean floor has also been felt well beyond the island itself. Due to the flexural rigidity of the earth's crust this subsidence may extend to a position west of Molokai (See Appendix). The subsidence due to the mass of Hawaii, added to the initial subsidence of Haleakala, is likely to have moved the original Haleakala shoreline below the depth of the saddle between Kohala and Maui.

During the last several hundred thousand years of earth history, while the primary geomorphic features of the Alenuihaha Channel were being shaped by constructional volcanism and island subsidence, there were eustatic sea level changes that effected the surface morphology of the channel floor. These sea level changes, caused by the growth and retreat of great continental glaciers, combined with continuous subsidence of the islands, alternately produced optimum conditions for calcareous coral reef growth and then conditions for reef drowning. These submerged reefs have been identified at several locations in the southeast Hawaiian Islands and are likely to be continuous around most of the submerged portions of the islands where they are not covered by other geologic processes.

Sedimentary processes are also capable of significantly changing the original geomorphic shape of the ocean floor. Since the islands emerged above sea level they have been exposed to subaerial erosive forces. These include chemical weathering, running water and ocean waves. During the long erosional history of Haleakala the debris stripped from the land has been deposited in the ocean and much of the coarser grained material has been moved down, and deposited on the submarine slopes of the island.

In summary, the principal geologic forces effecting the submarine morphology of the Alenuihaha Channel are: (1) constructional volcanism, (2) island subsidence, (3) reef growth and (4) sedimentation. Each of these processes, alone and in conjunction with the others, are capable of producing topography that will make unacceptable cable spans. An example of topography framed by a drowned reef may be the 35 - 40 degree slope between depths of 870 and 900 meters on track 39, this is about the depth where reef IV (see Appendix) should be located in this area. The effect of sedimentation is most clearly seen on the Maui slope of the channel where debris flow deposits, darker flow like features on the SeaMARC II images, appear to mantle the slope. Curved scarps on the Maui slope that may be flow fronts or drowned reefs appear buried in places by the debris flows and it is these areas that may provide a suitable cable route.

## 4: CONCLUSIONS

### 4.1 METHODOLOGY AND EQUIPMENT

The bottom roughness sampler, using both the pressure transducer and the echo sounder to evaluate precise bottom topography, worked extremely well and within the tolerances required of the cable laying analysis ( $\pm 15$  cm).

The SeaMARC data has been extremely valuable in providing an overall "picture" of the bottom and has been a key ingredient in determining future cruise plans.

Methods have been developed to relate roughness to potential cable spans and bend radii. These methods are essential to the meaningful interpretation of the roughness data.

### 4.2 CABLE ROUTE

The primary accomplishment of the preliminary cruise has been that the general level and distribution of roughness along the cable route in the Alenuihaha Channel has been successfully identified and interpreted relative to laying the HDWC commercial cable.

The cruise results have greatly increased the program's confidence that an acceptable cable route can be found.

Precision cable laying will probably be required during the commercial program but, if required, it will be isolated to specific locations and be a small percentage of the overall cable laying. The most difficult cable laying problems are anticipated to be between 900 m and 1200 m on the Kohala slope and between 1000 m and 1300 m on the Maui slope.

Many major roughness concerns prior to the cruise have been eliminated, such as the existence of continuous and impassable escarpments or a bottom that is extremely rough everywhere.

The first cruise has not identified a continuous path across the Alenuihaha Channel nor has it identified the width of the path in any of the areas where the roughness was acceptable. It has, however, identified potential paths and likely areas.

Large areas have been identified that are relatively smooth and do not represent a major challenge to cable laying, from the standpoint of bottom roughness. These areas include the lower portion of the Kohala slope, the bottom of the channel, and the shallow water near Kohala.

The Kohala slope is generally extremely rough at the top (1000 m) and smooth below 1200 m. The most promising cable route on the Kohala slope is along track 10 or 40, on the western side of area A. There is, however, a great deal of variability in adjacent tracks only a few hundred meters apart leading to the conclusion that any path over the top of the Kohala slope will be narrow.

The Maui slope is less easily characterized, but the rougher regions are between 1000 m and 1400 m. The most likely paths are along the western edge of area B, tracks 41 and 31 being the most promising (but not without spans). Above 1000 m, there appears to be many choices for acceptable paths.

A path has not been found from the Kohala slope to the Big Island, but the one track surveyed showed was mostly a smooth bottom, with isolated rough spots. Due to the wide degree of freedom in selecting a path over this very large region, it is believed that an acceptable path can easily be found.

The cruise has identified areas which will require more survey work during the second cruise. Most notably these areas are at the top of the Kohala slope in the vicinity of track 10 between the 1000 and 1200 m contours, and along the Maui slope west of, and including Track 41 between 1000 m and 1400 m (see section 4.4).

The position of the tracks and the obstacles identified along the tracks are only known to an accuracy of approximately 150 m, unsuitable for the identification of an actual cable route.

#### 4.3 BOTTOM SPANS AND CABLE BEND RADII

The number and location of critical cable spans in a mathematically laid cable on the surveyed bottom topography has been the means of evaluating the HDWC cable compatibility with a given survey track. This method has proved valuable in isolating problem spots within the survey area and along a given profile.

In general, it is better to lay the cable at a low tension such that it conforms better to the bottom than at a high tension, fewer unacceptable spans resulting.

Critical bend radii, when they do occur in the data analyzed, nearly always occur in association with a critical span. As a result, while analyzing bottom roughness data, it is sufficient to search potential cable paths for critical spans.

#### 4.4 FURTHER SURVEYS

More survey work is required in the Alenuihaha channel for the following reasons:

1. A continuous, span-free path has not been found across the channel.
2. The width of the paths that are acceptable has not been determined; this is critical in determining the difficulty in laying the cable.
3. The bottom location of paths and features from this survey is only  $\pm 150$  m, insufficient for precise cable laying.

Figure 41 illustrates the recommended areas for further surveying. Areas A and B have been shifted slightly to the west and individual routes, based both on the BRS and the SeaMARC data are suggested. These recommended areas are based on the following:

1. The bottom and the shallow regions above 900 m on both sides of the channel do not appear to present a significant obstacle to the HDWC cable nor does it represent a significant challenge in determining the commercial cable feasibility. Although a specific route has not been identified, it is believed that a route can be easily found across these areas.
2. The mid water depth areas on both sides of the channel are the most significant challenge to the ability to lay the Hawaii cable. The feasibility of laying the cable cannot be addressed without looking further at these areas.
3. The recommended paths through areas A and B are based on the most promising BRS survey tracks and the SeaMARC data showing areas of potential paths.

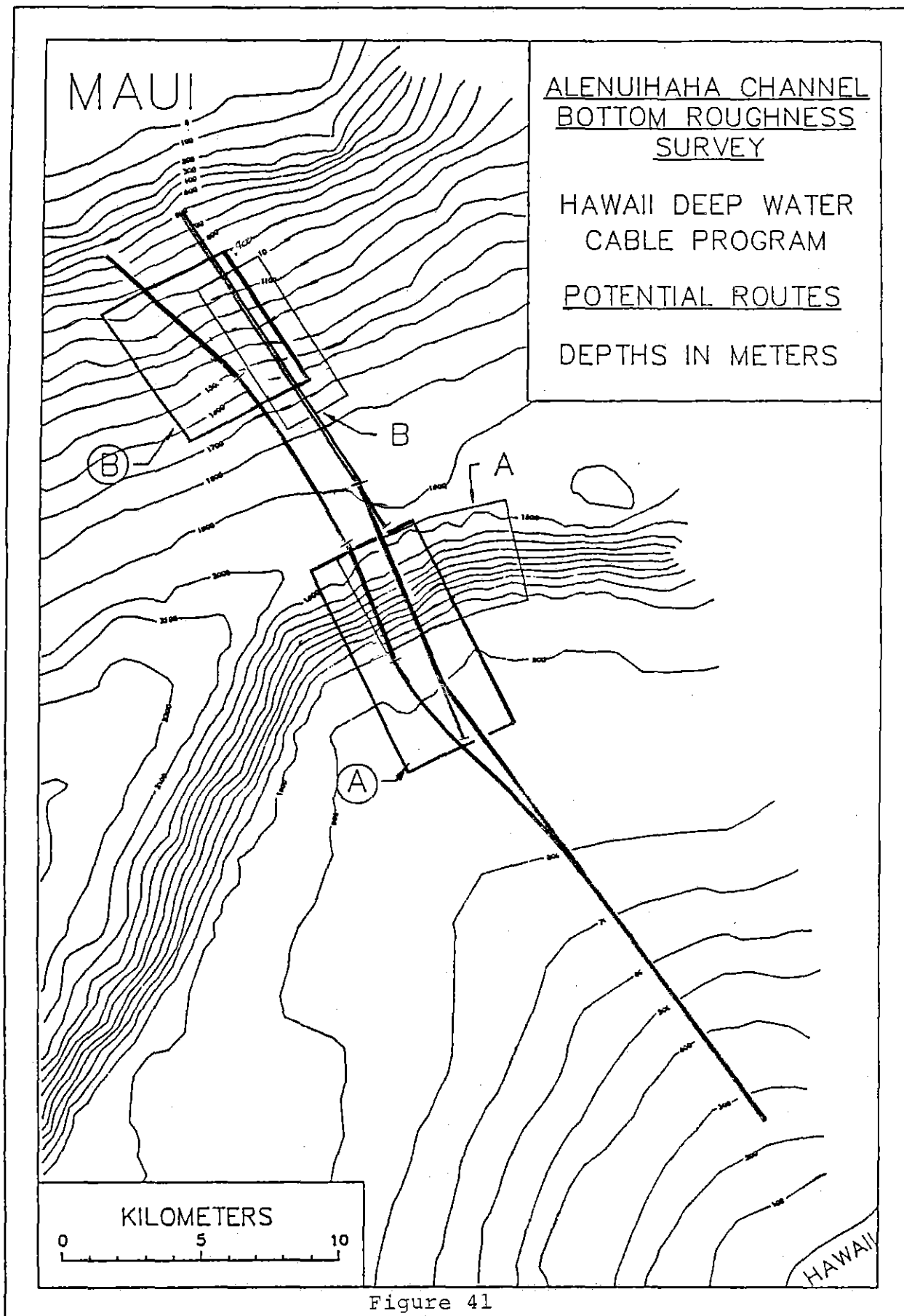


Figure 41

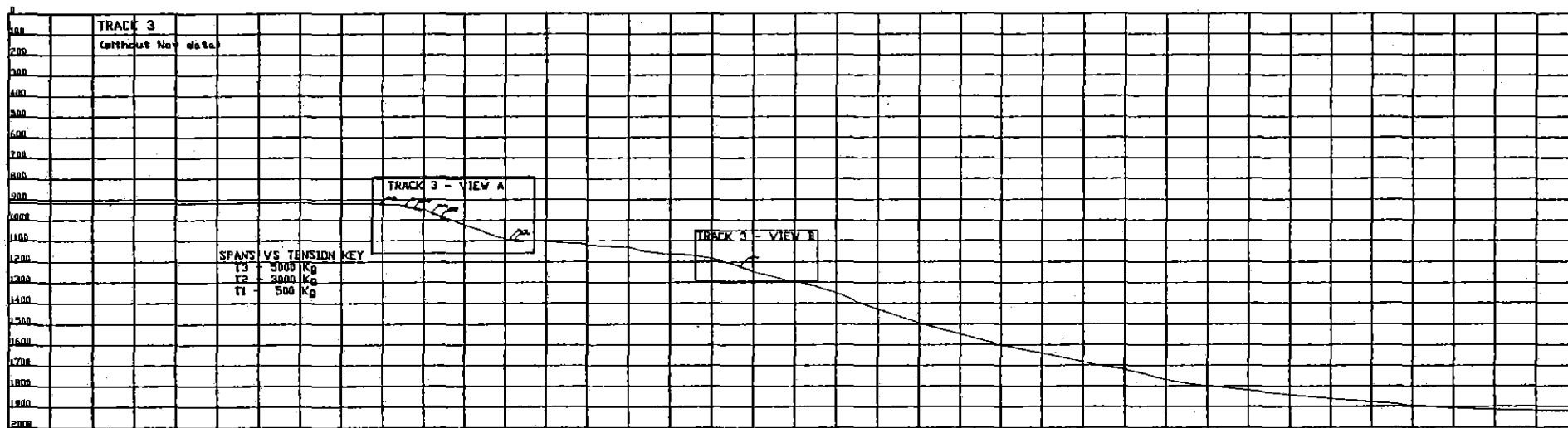
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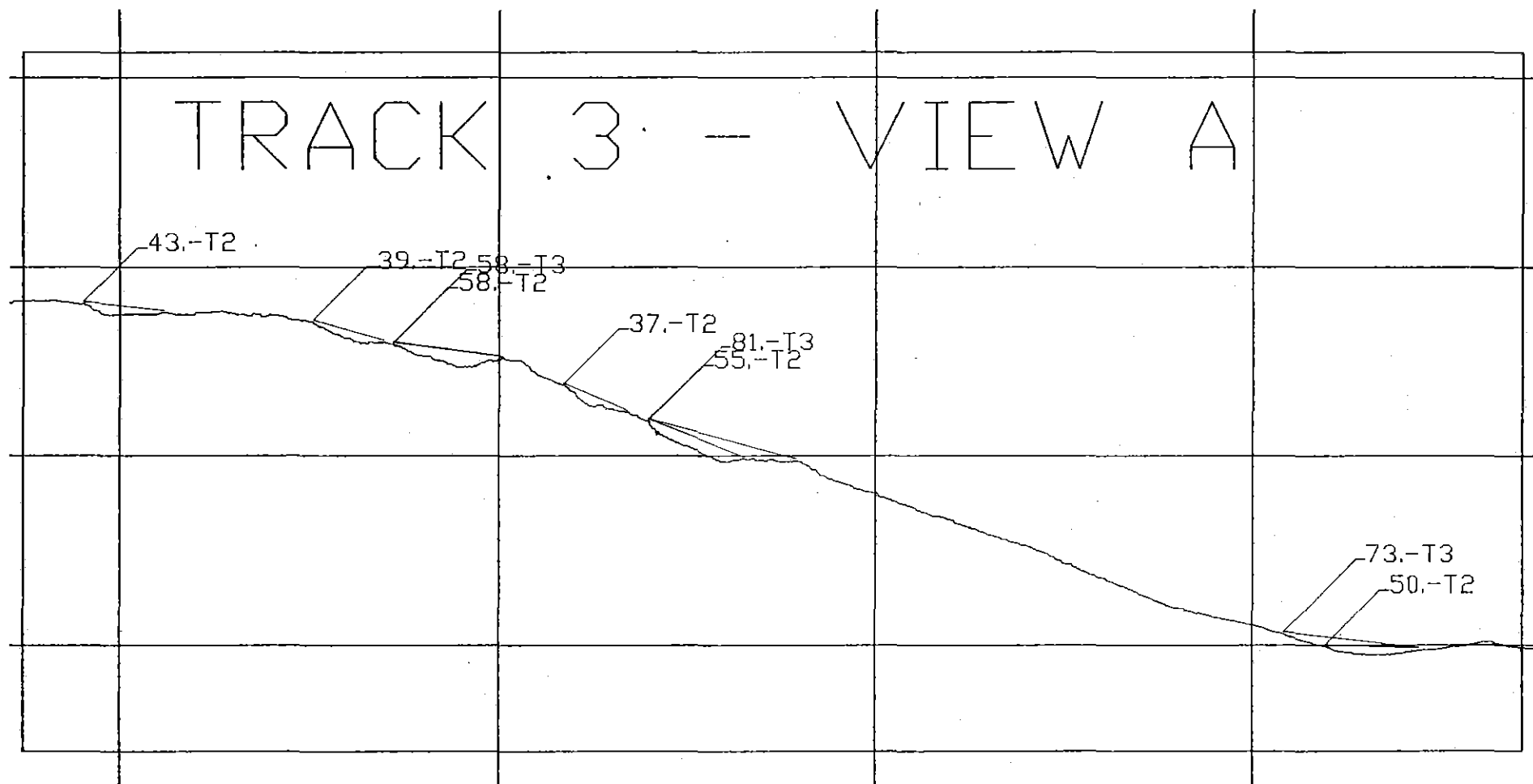


**APPENDIX A**

**BRS PROFILES, KOHALA SLOPE**

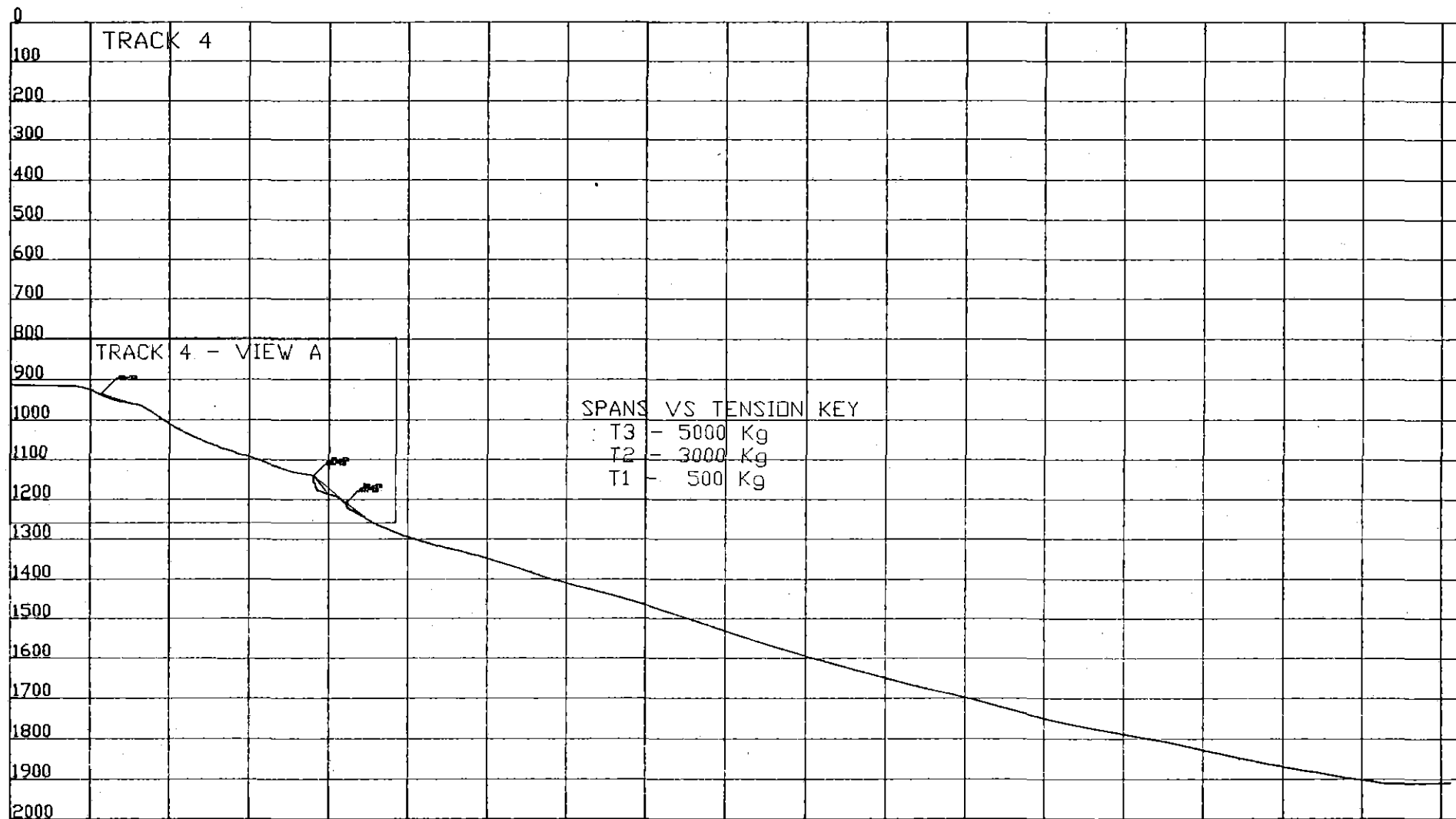


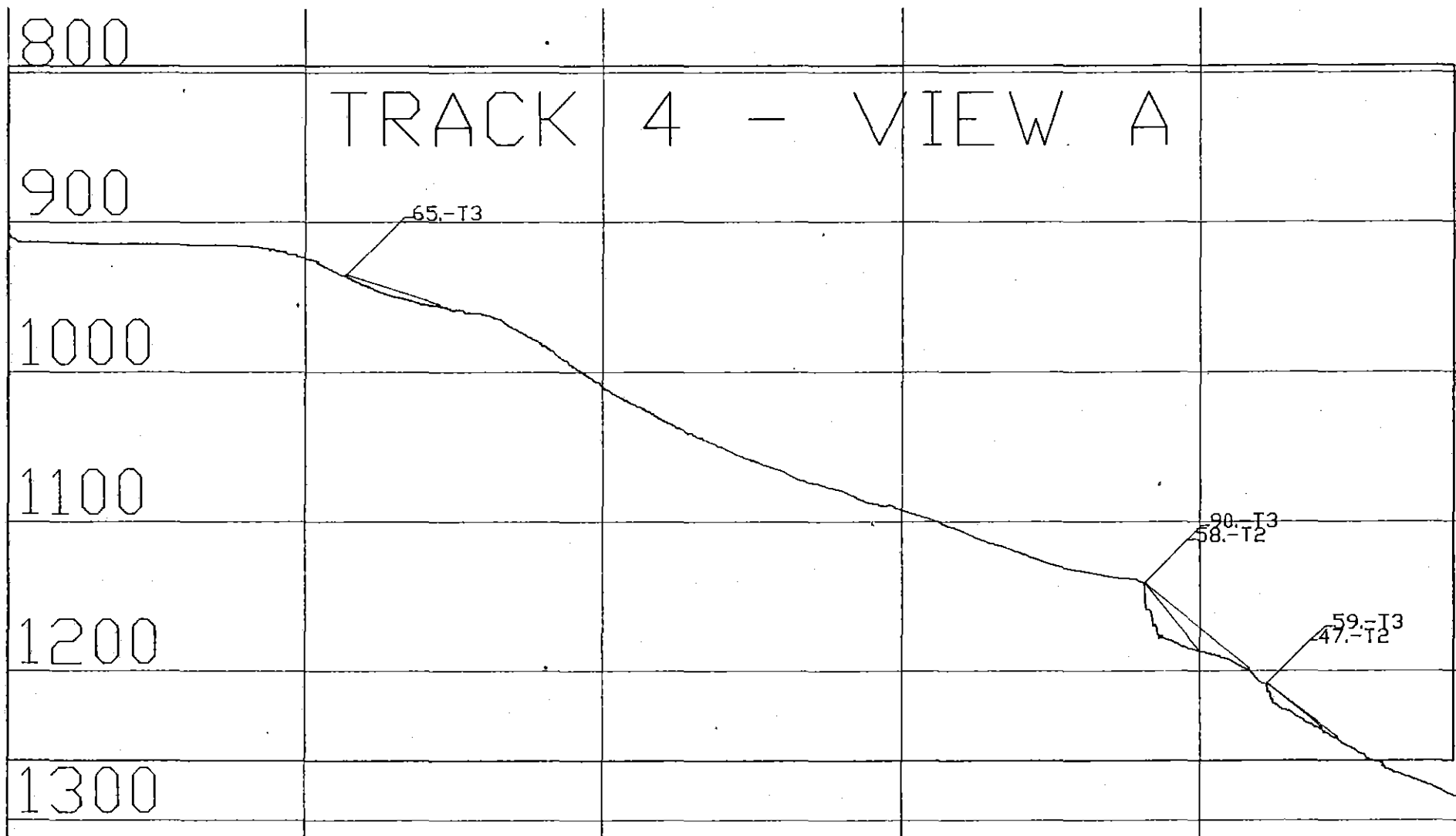
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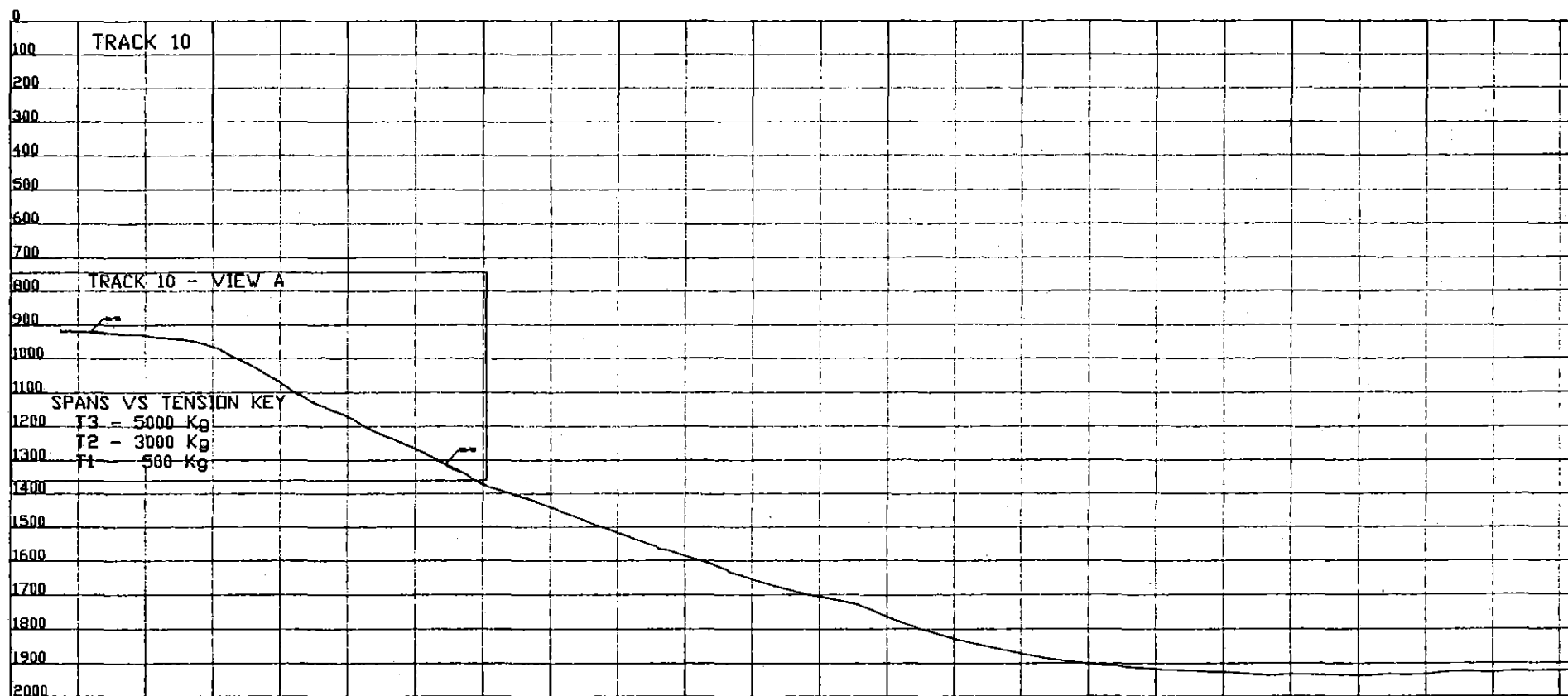


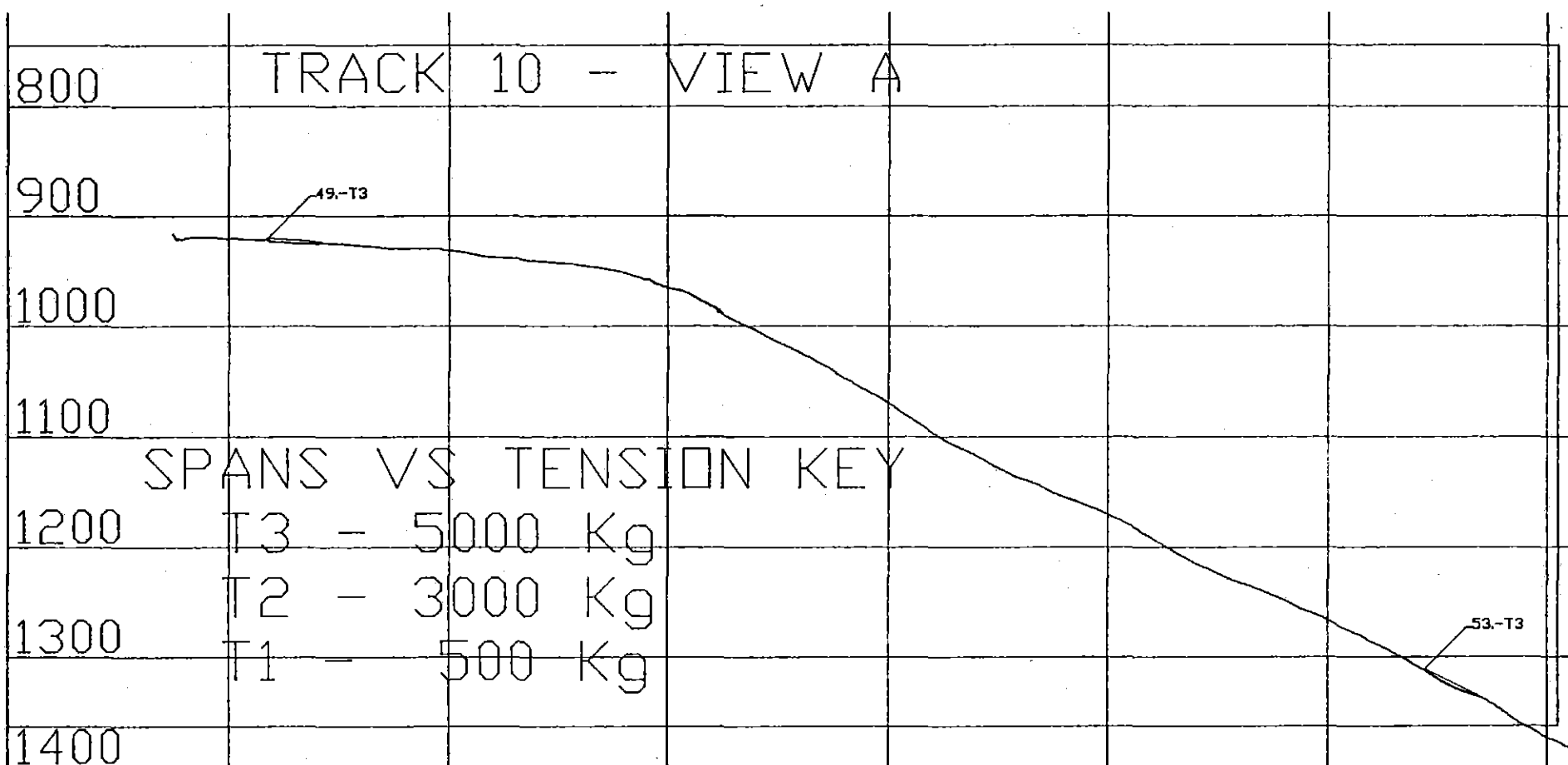
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48.-T3

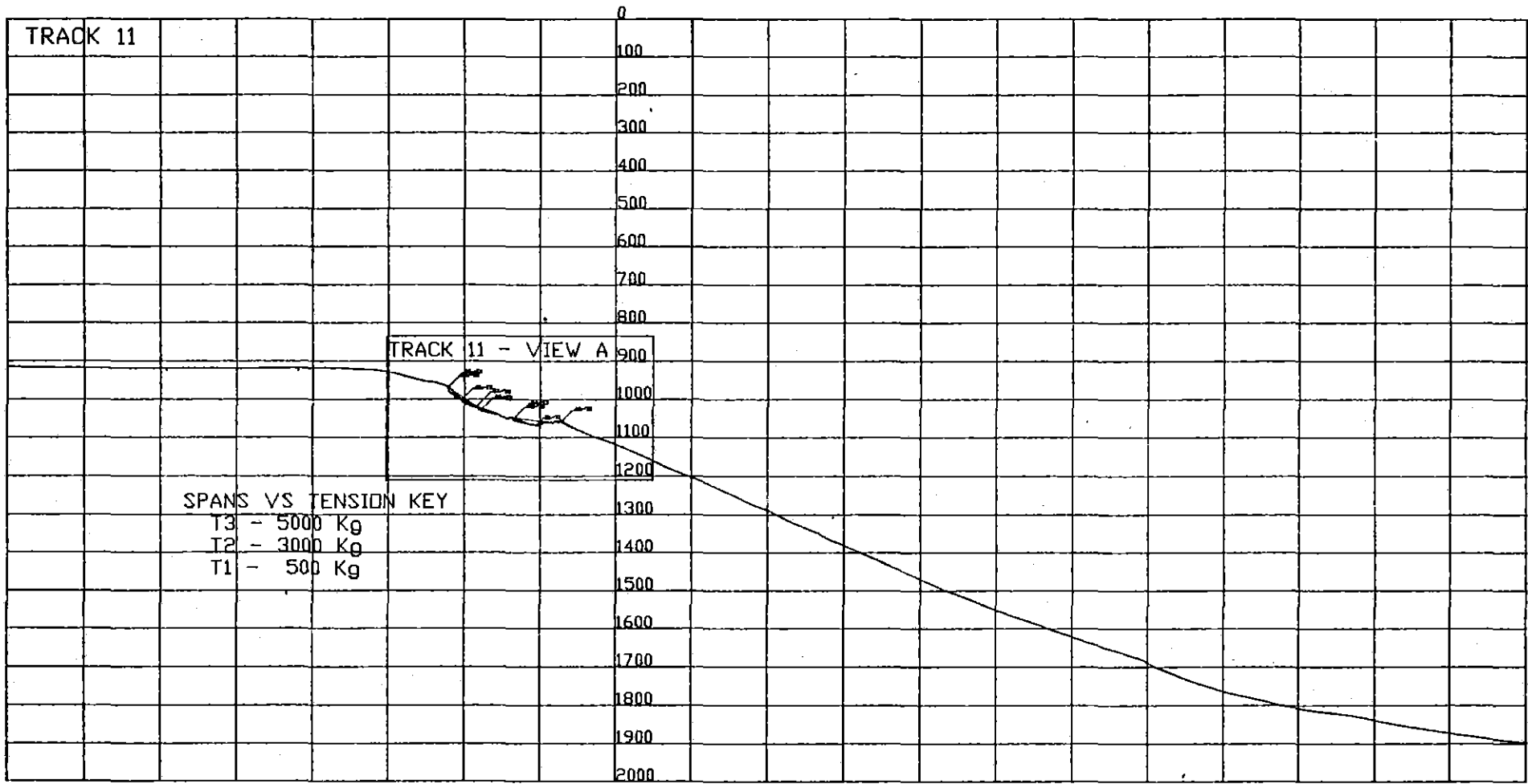




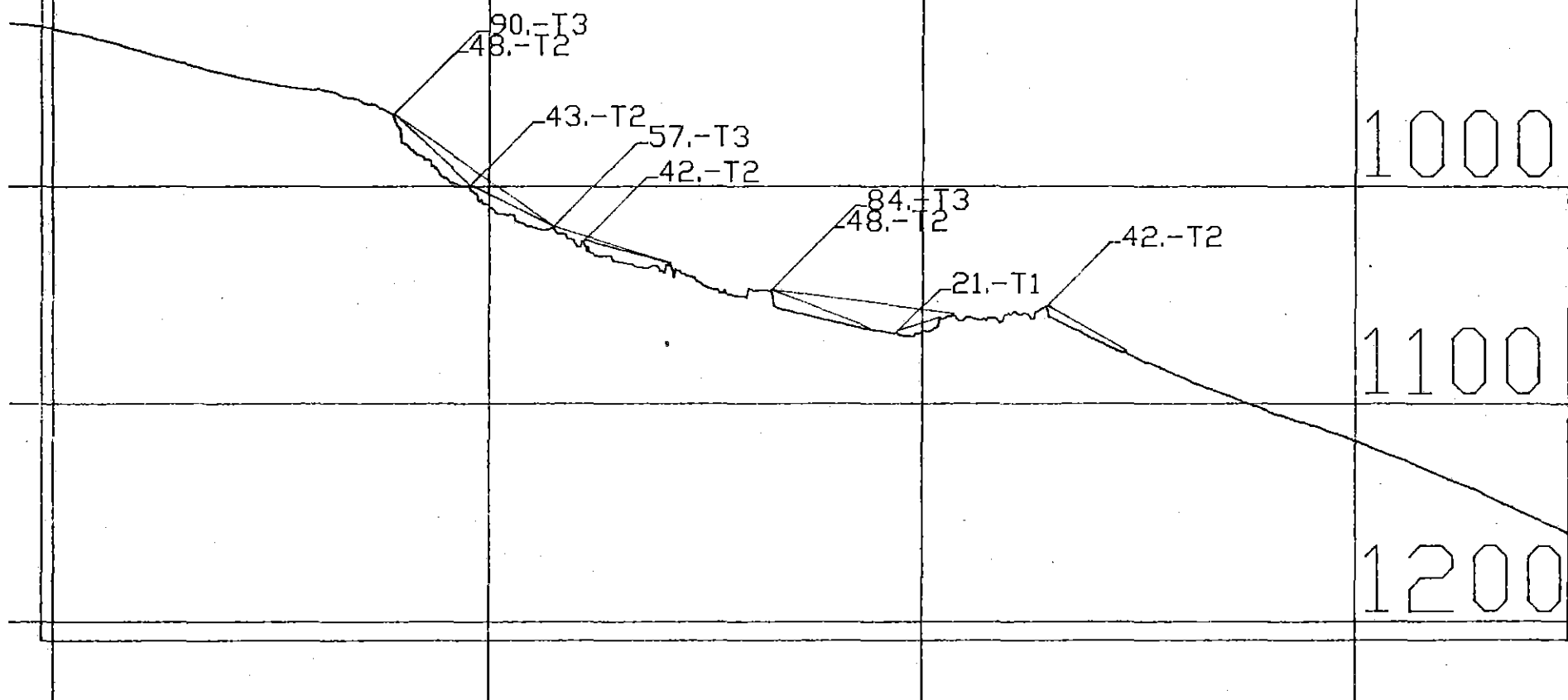


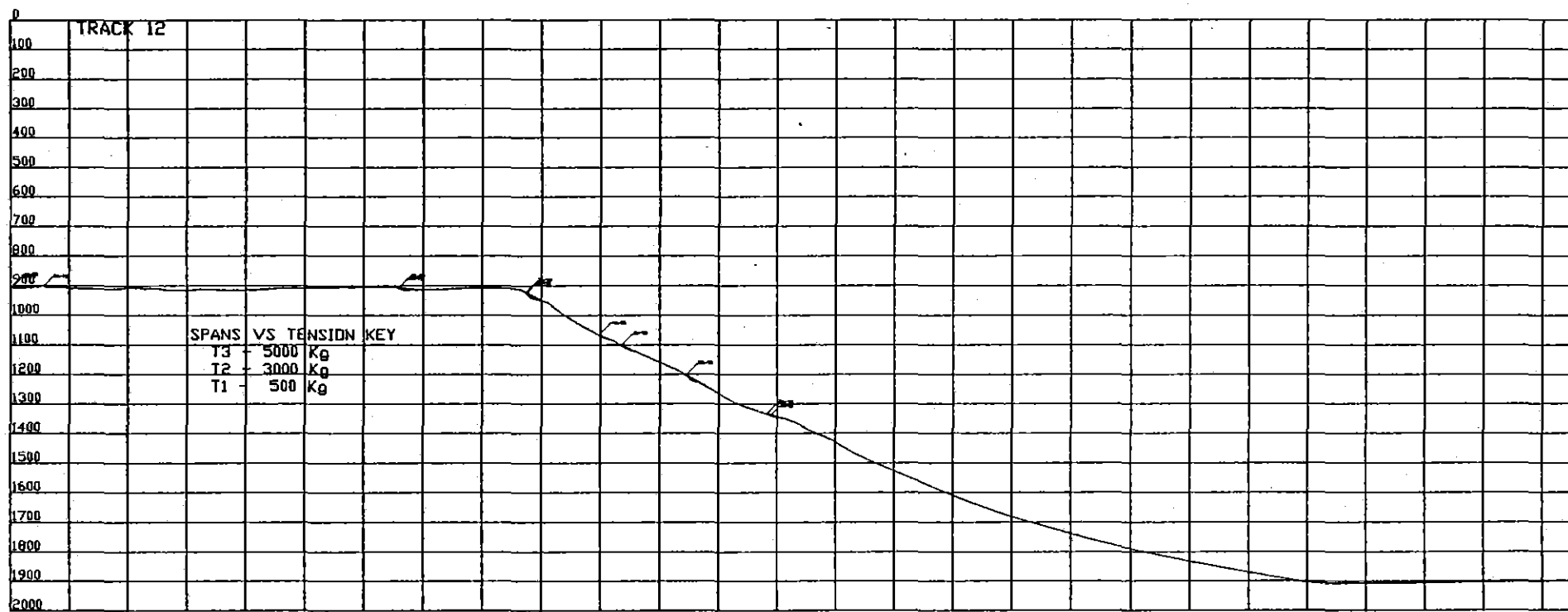




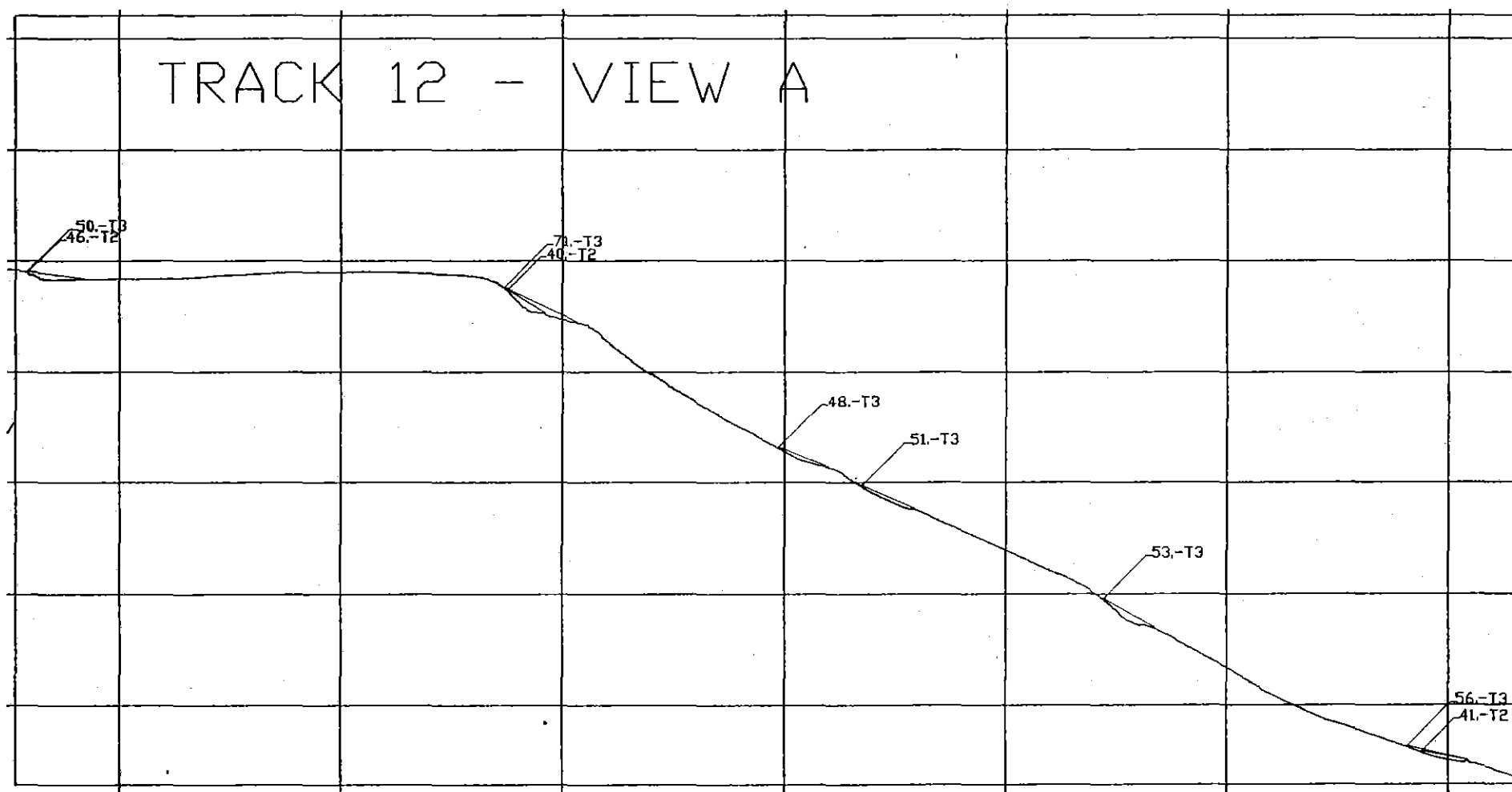


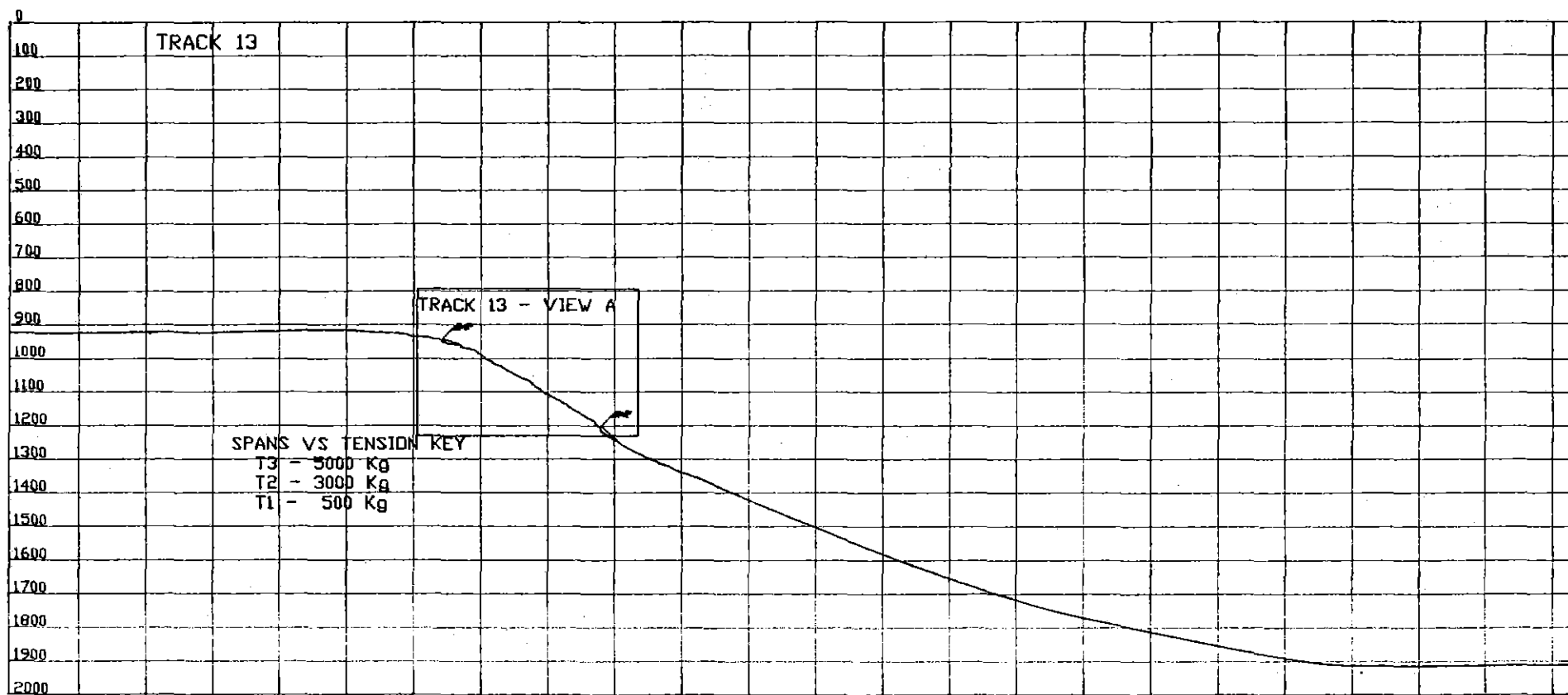
# TRACK 11 - VIEW A 900



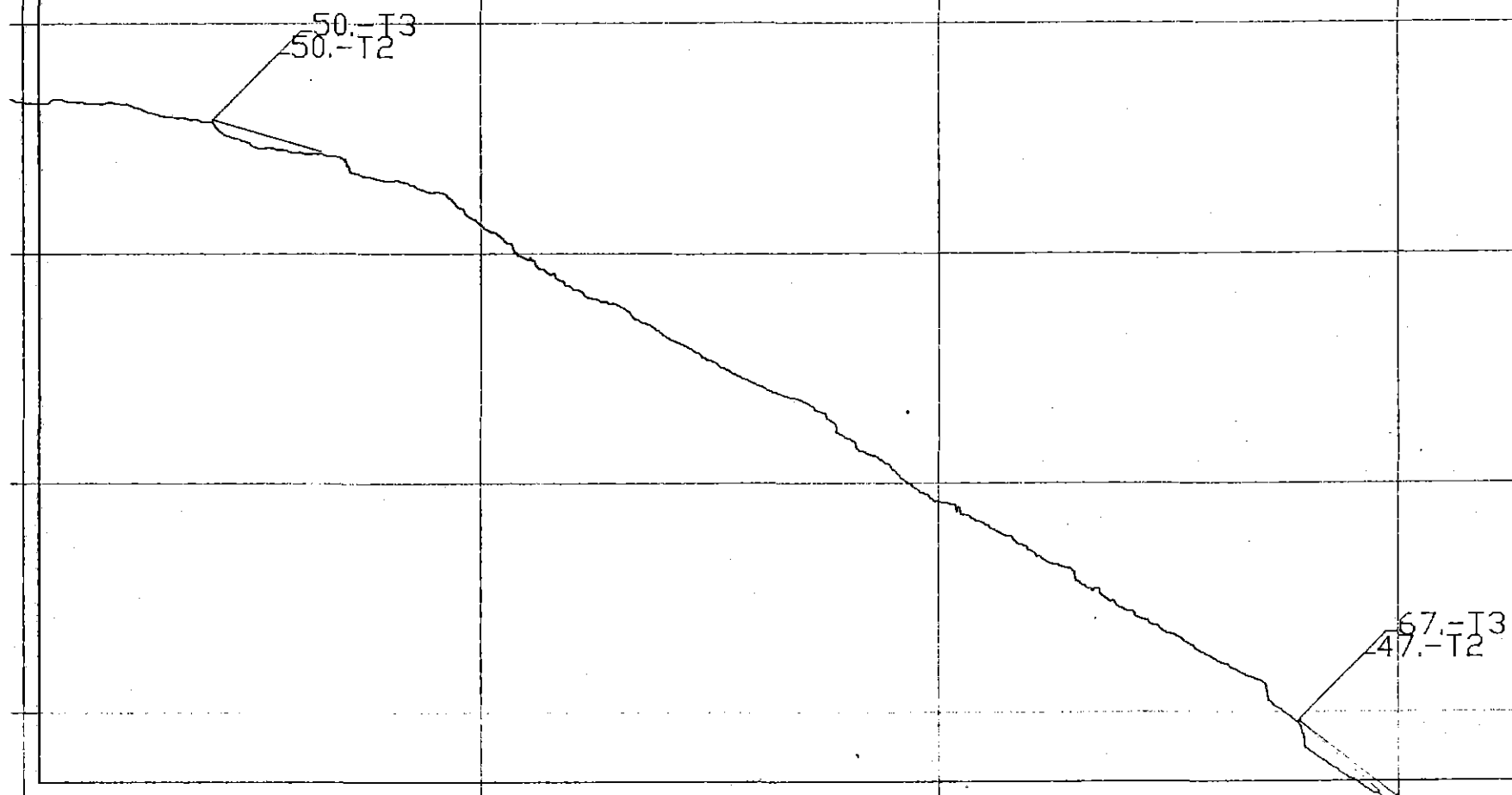


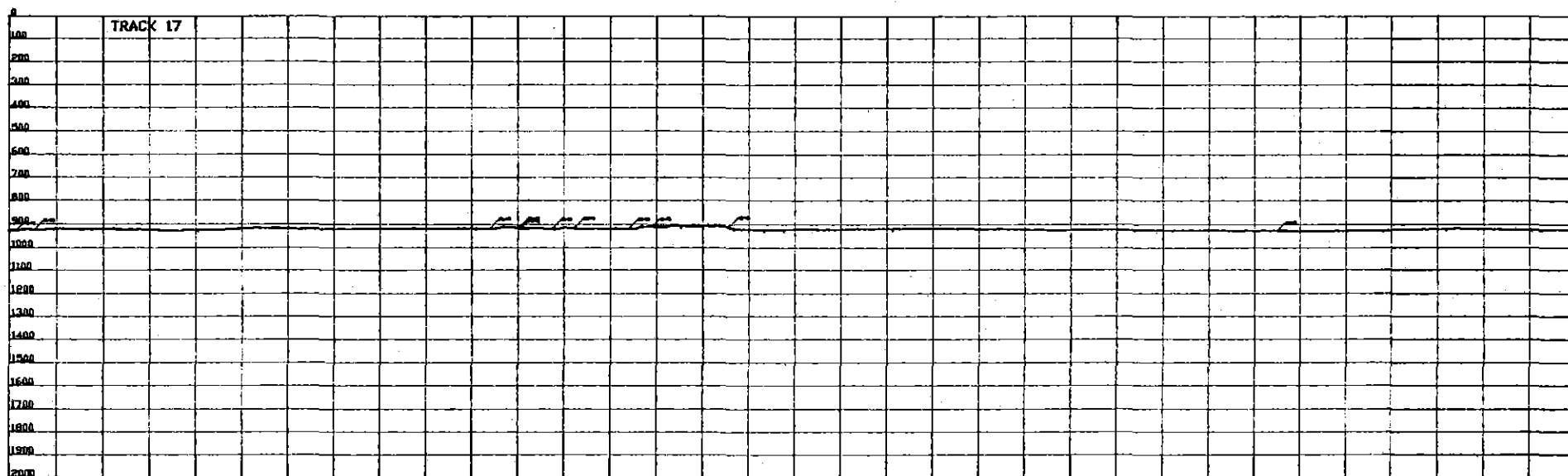
# TRACK 12 - VIEW A





# TRACK 13 - VIEW A





# TRACK 17 - VIEW B

53.-T3

57.-T3  
40.-T2

51.-T3

53.-T3

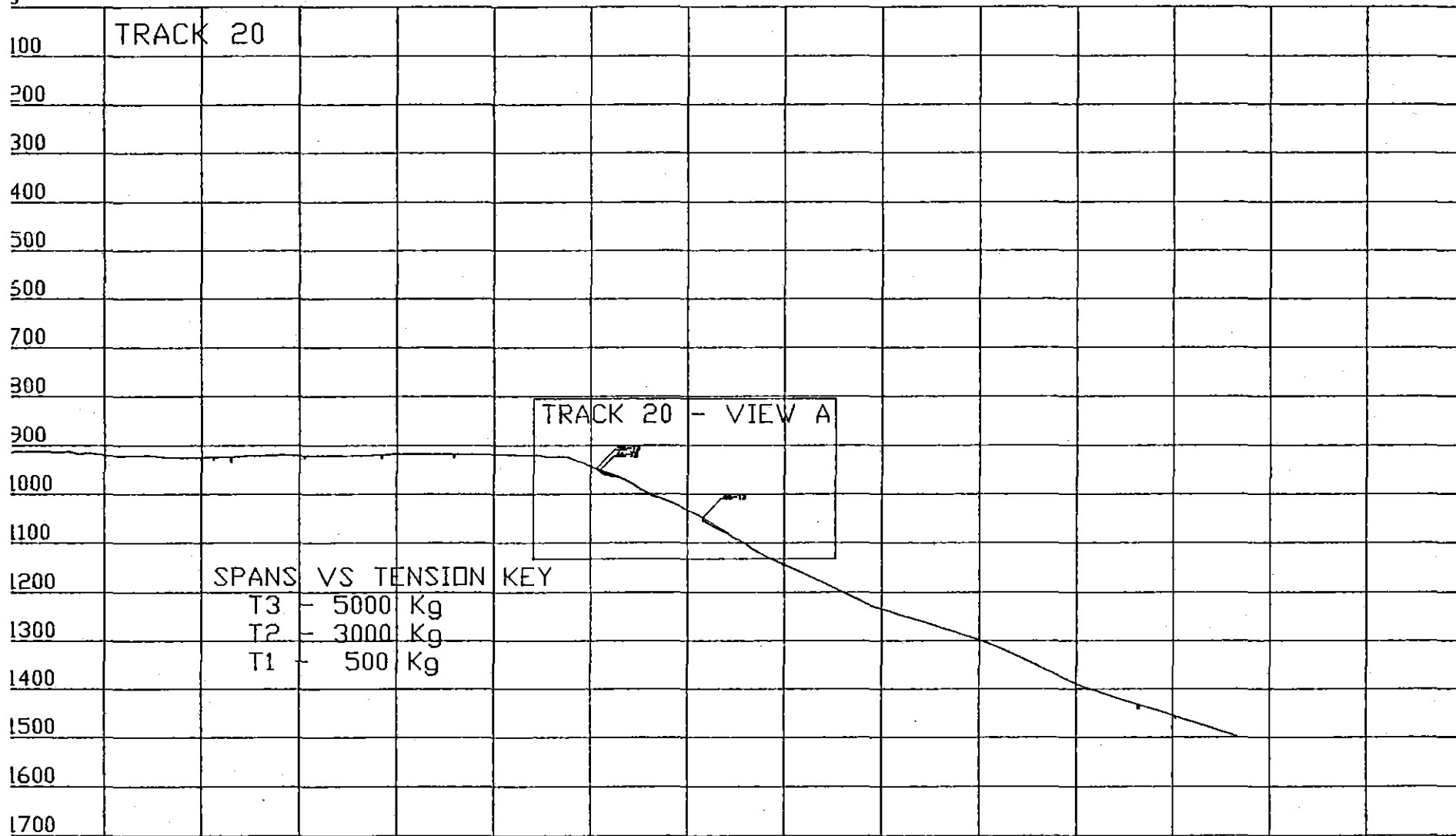
54.-T3

40.-T2

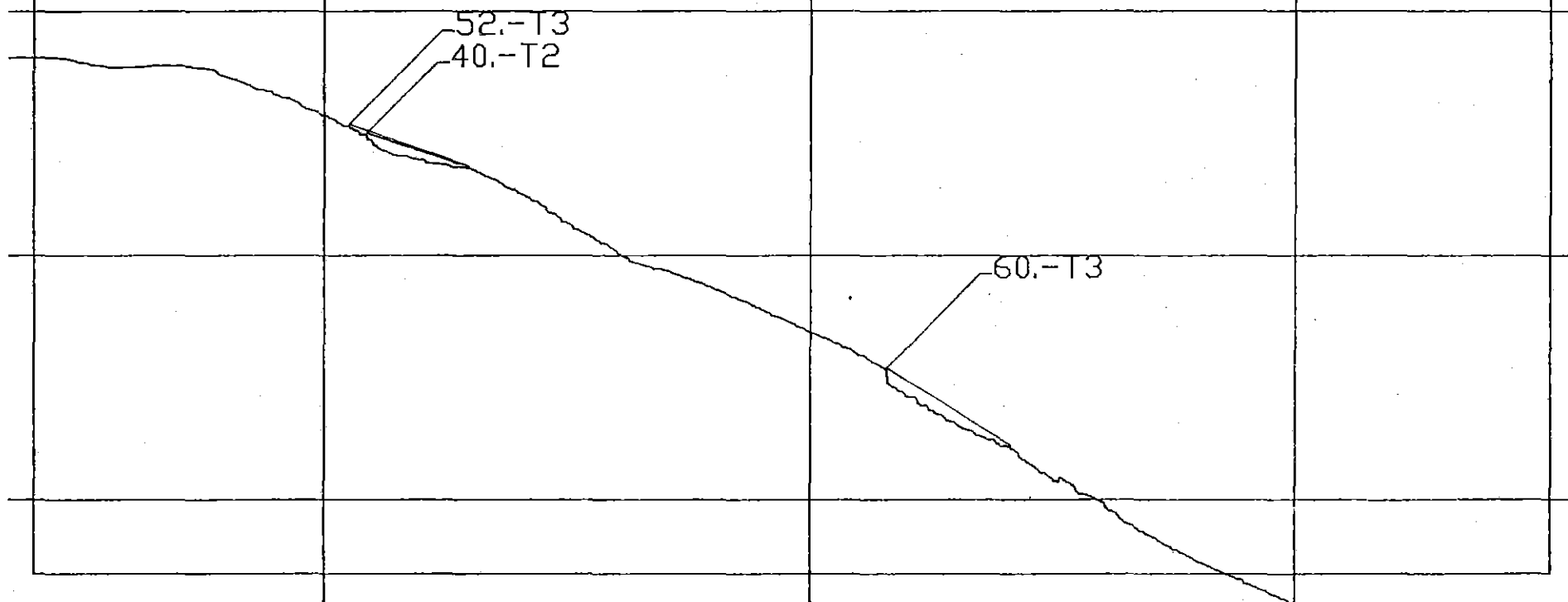
62.-T3

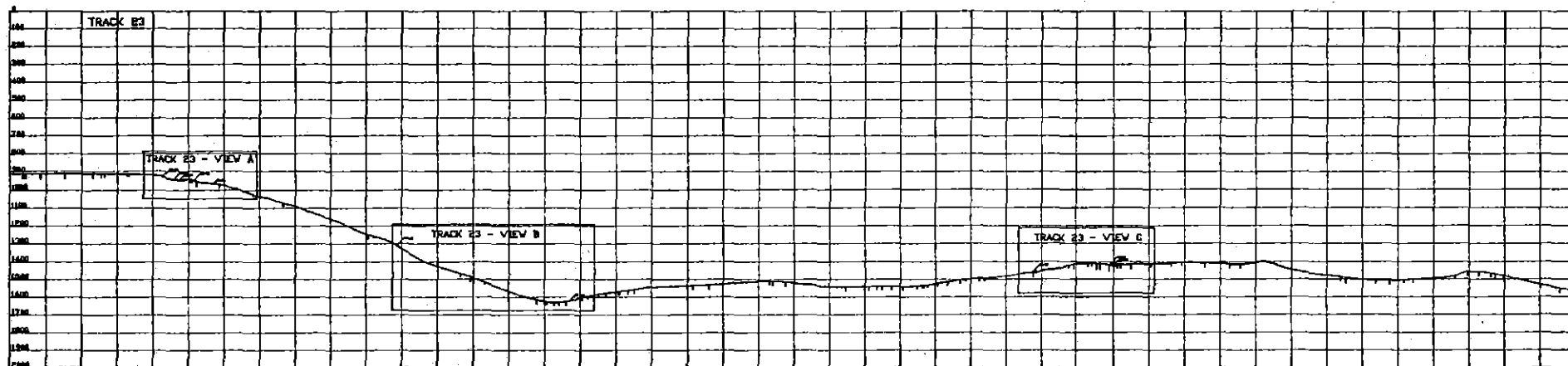


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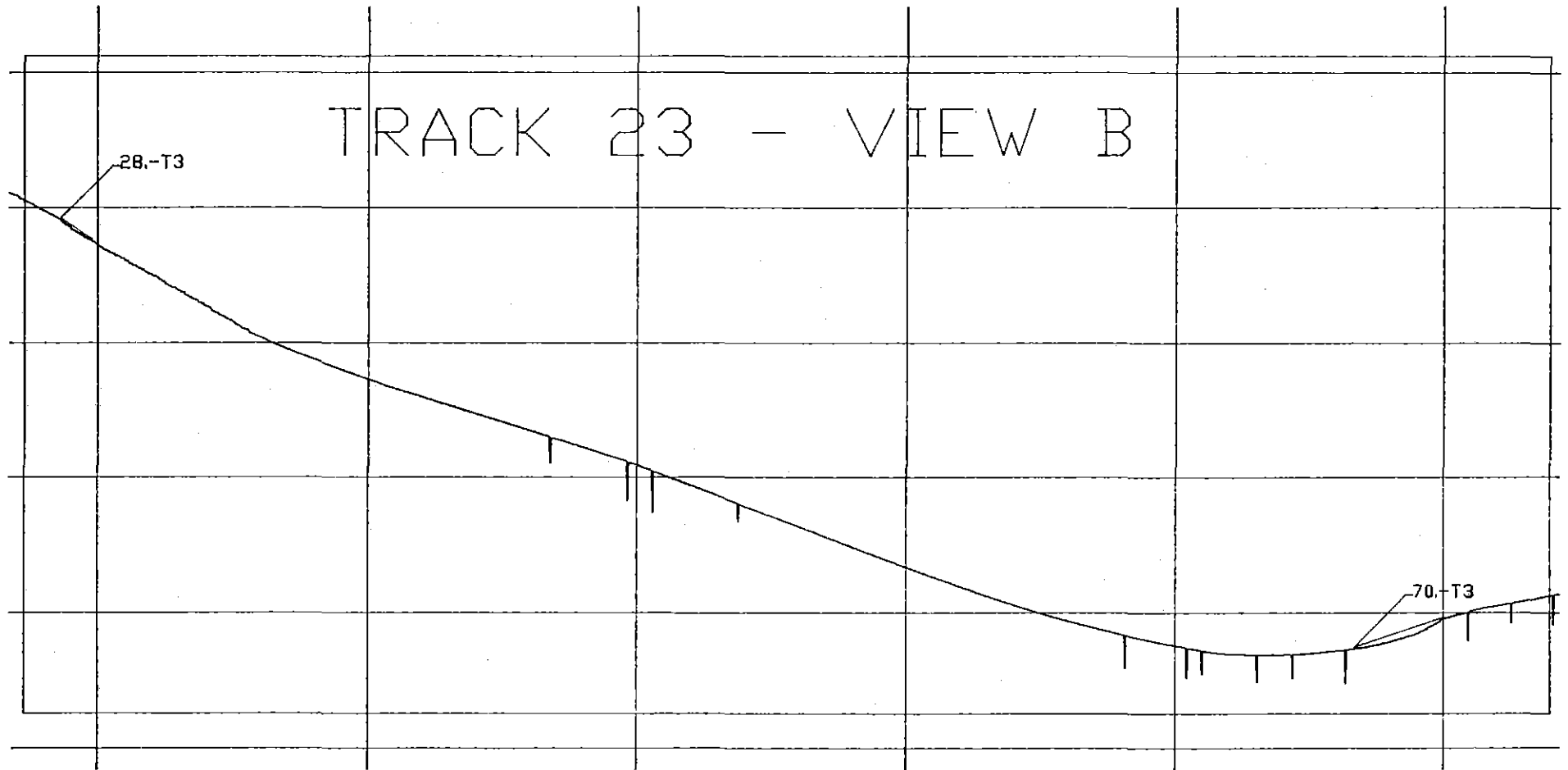


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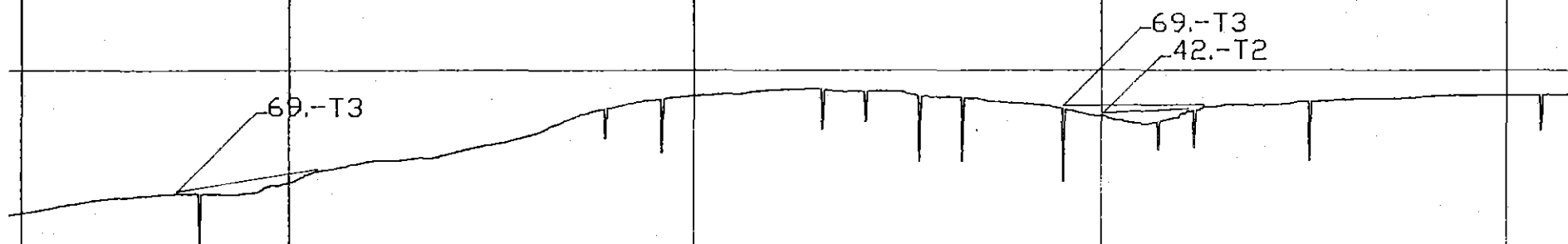




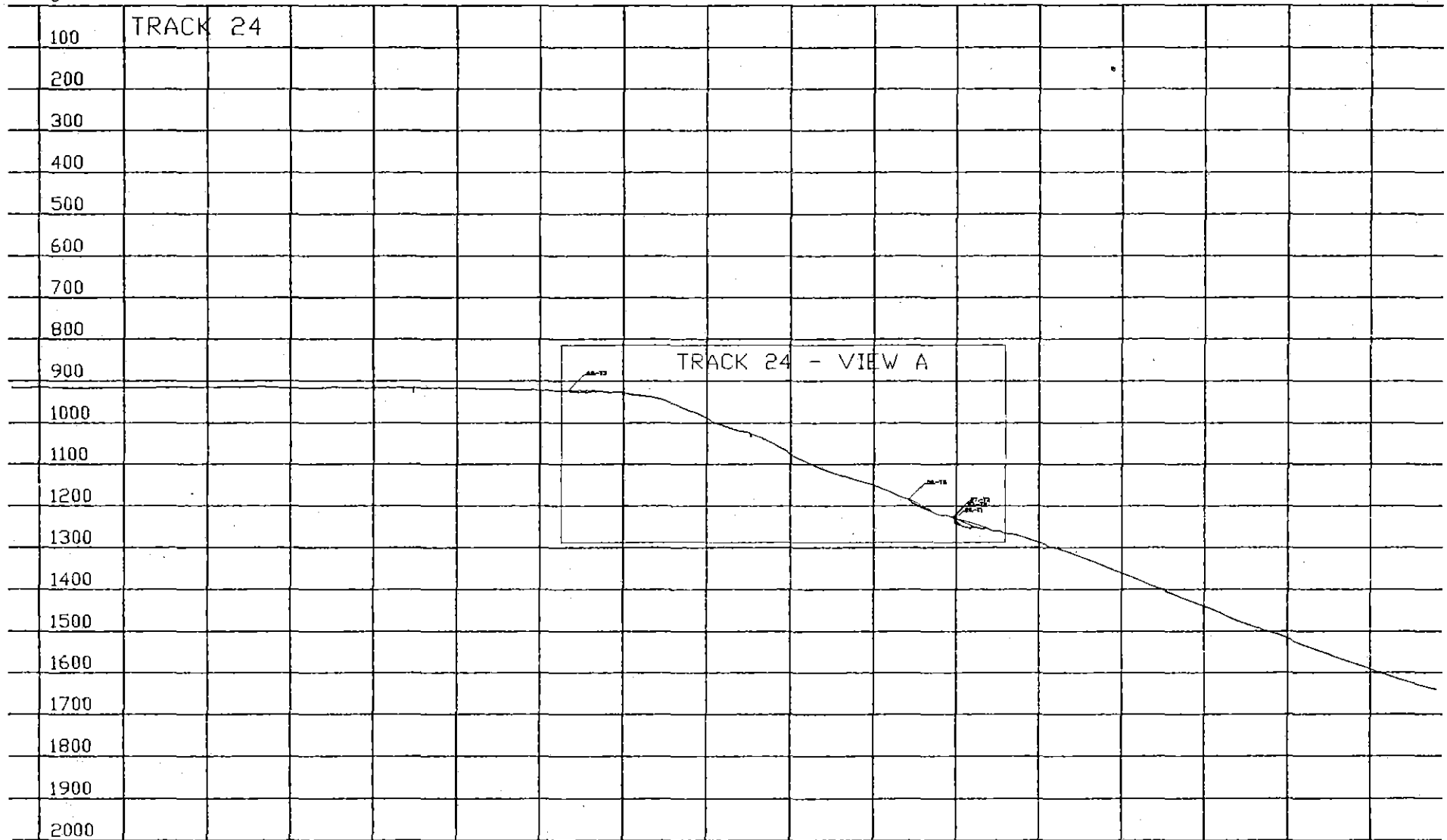
# TRACK 23 - VIEW B



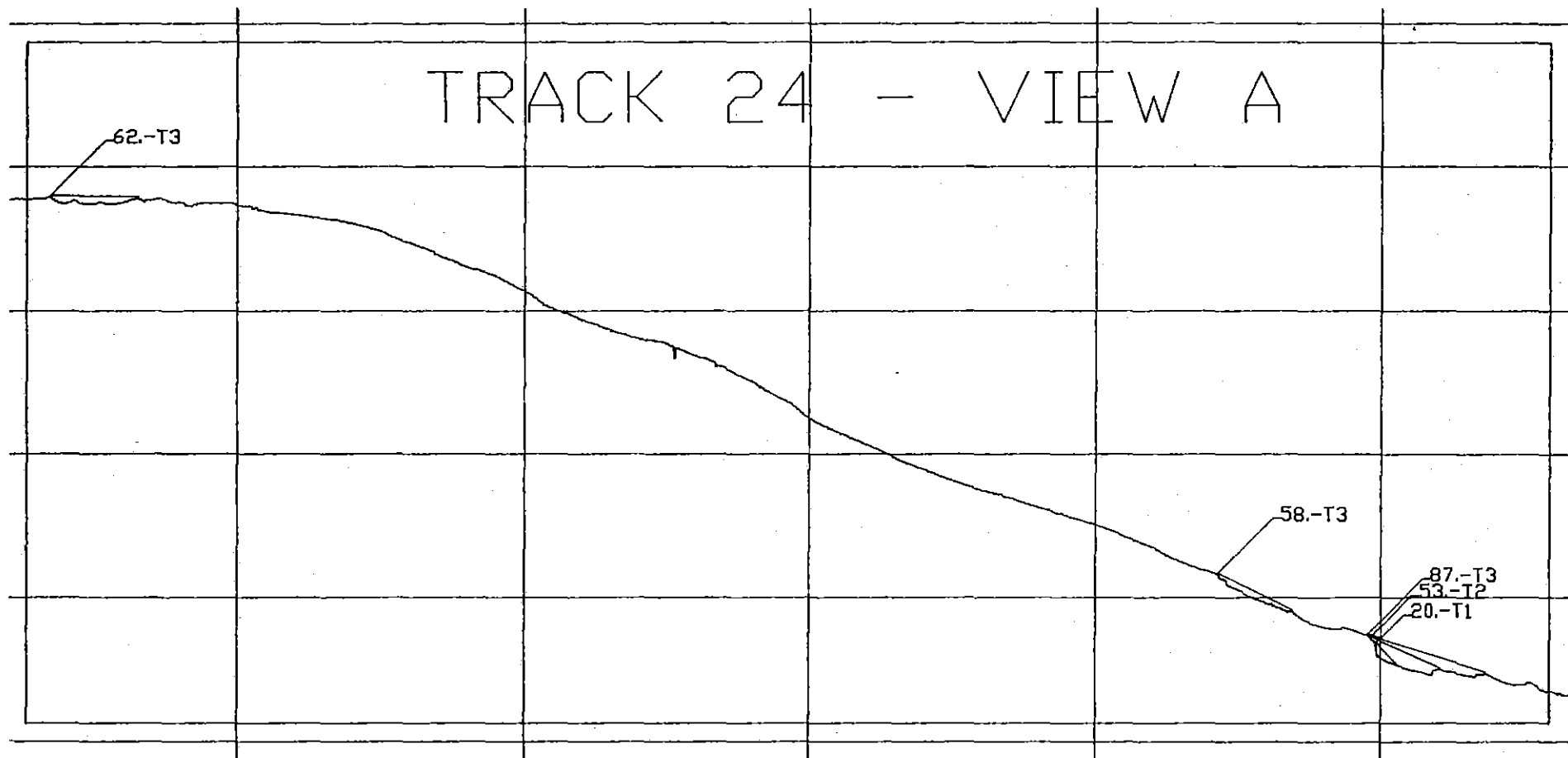
# TRACK 23 - VIEW C

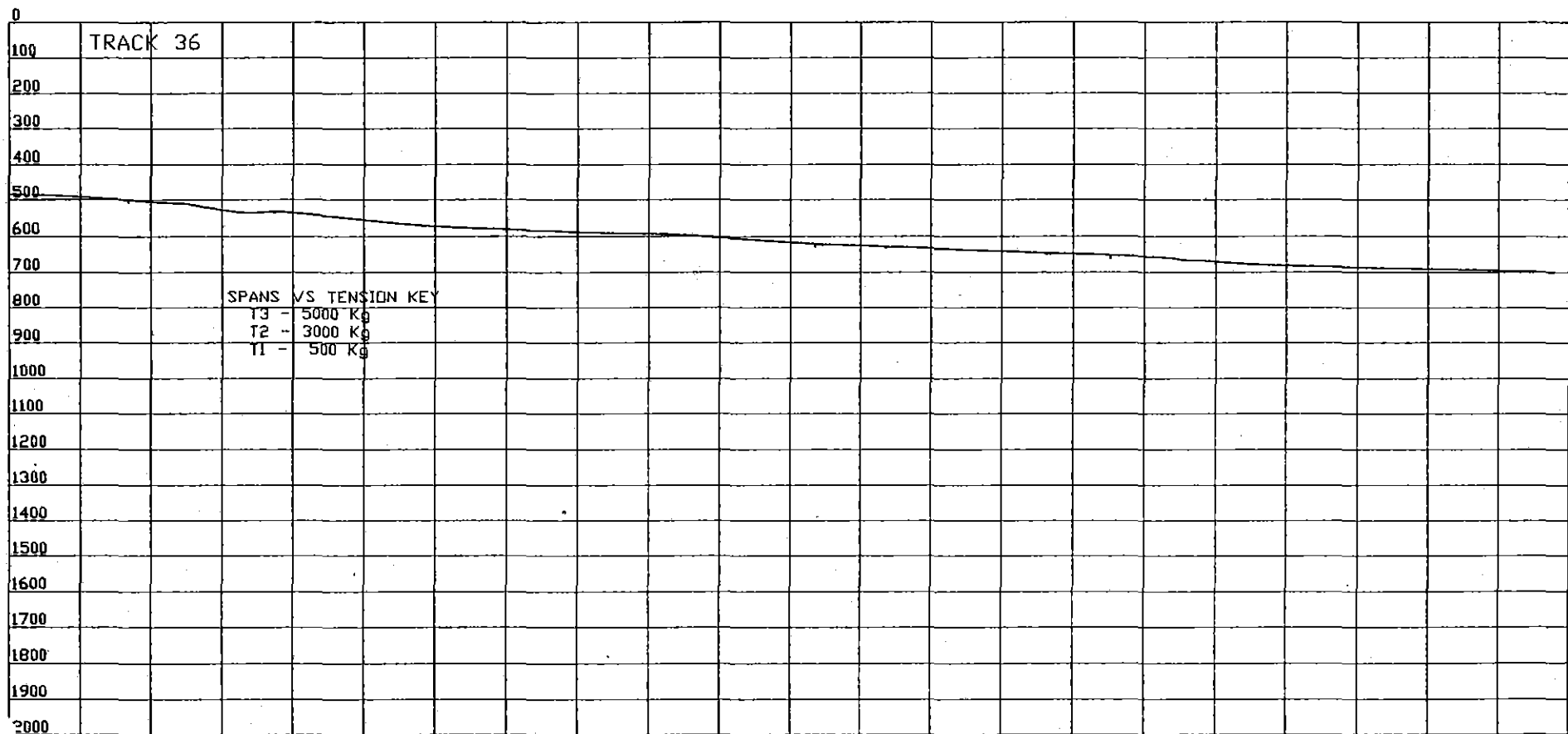


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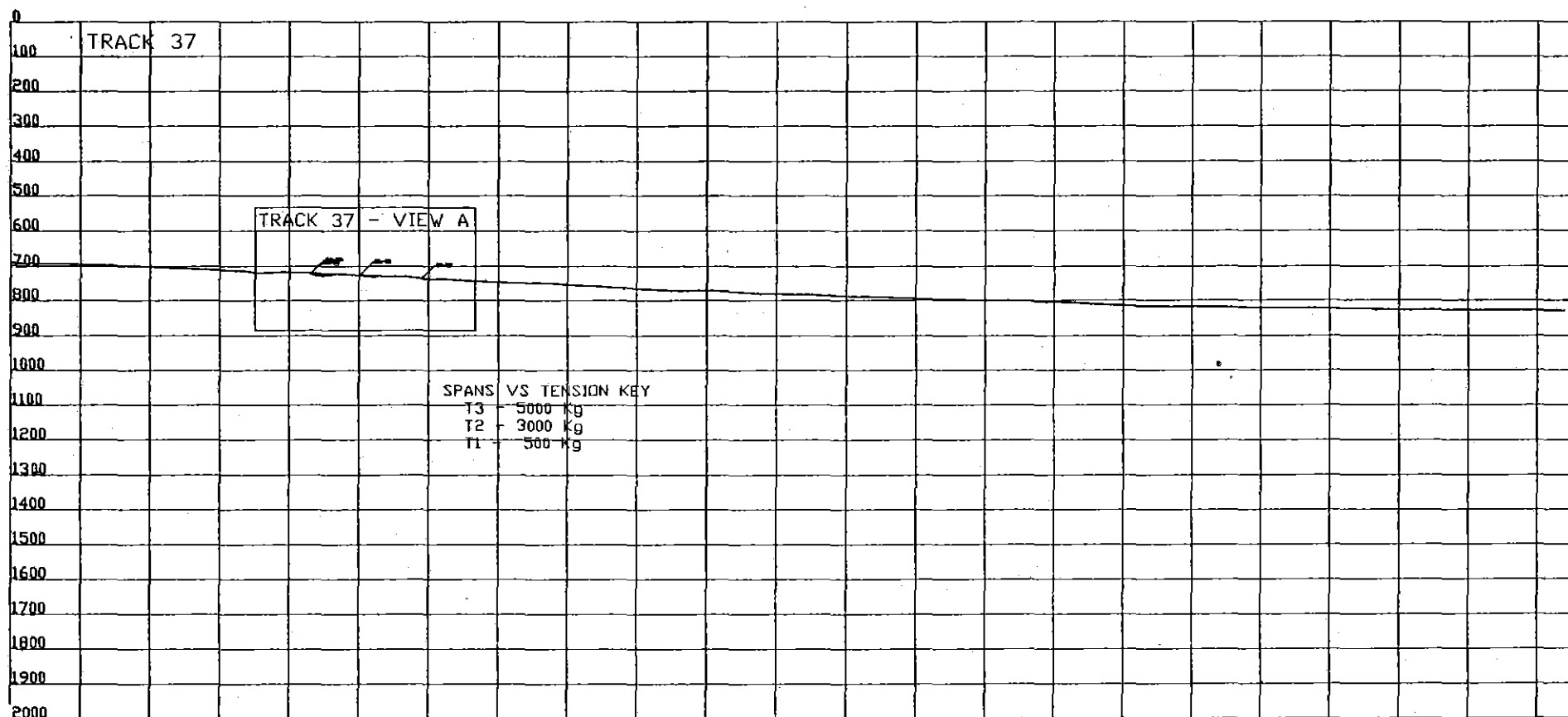


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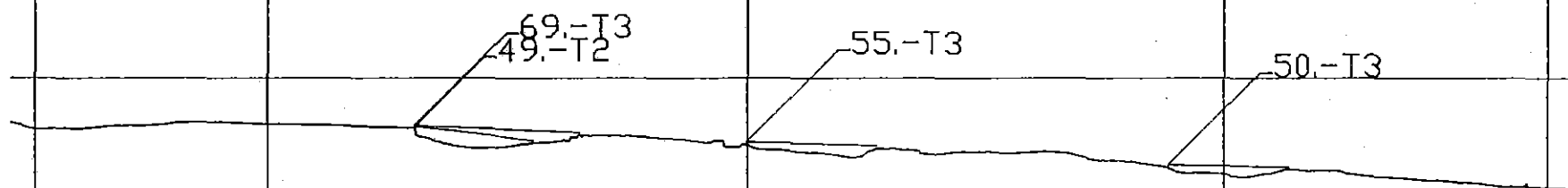




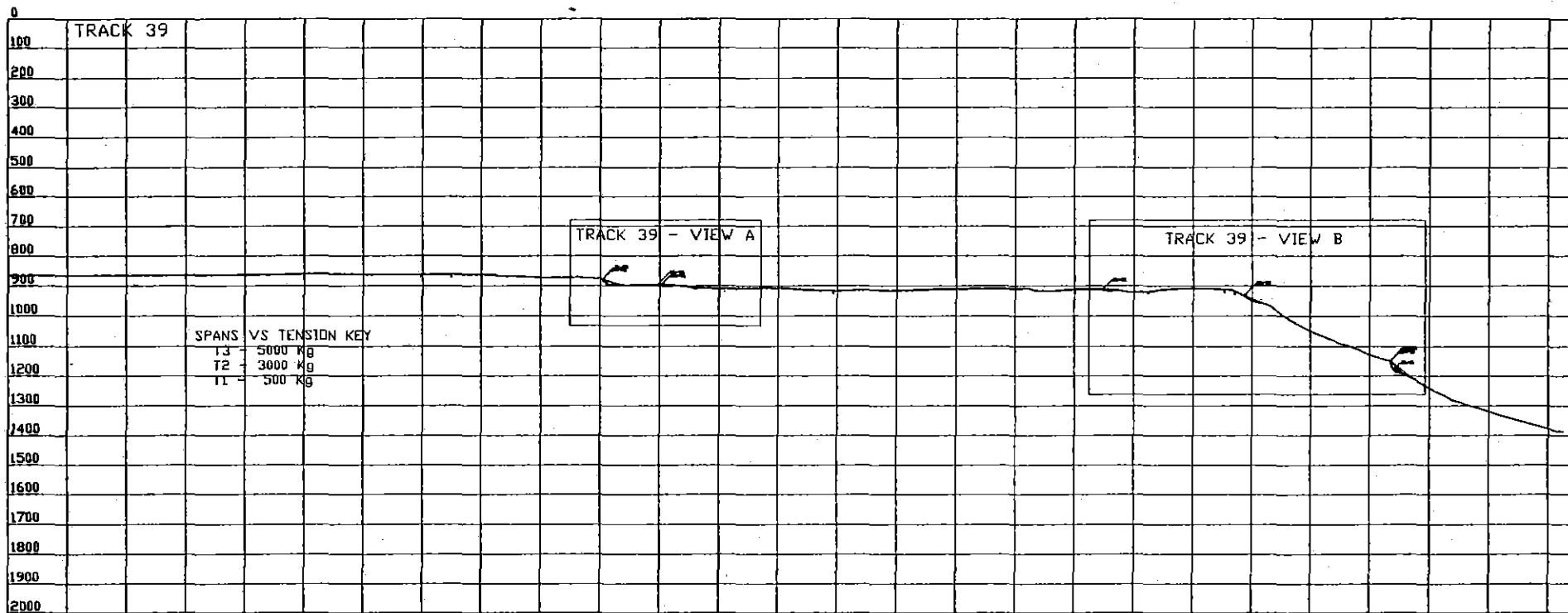




# TRACK 37 - VIEW A



[illegible]

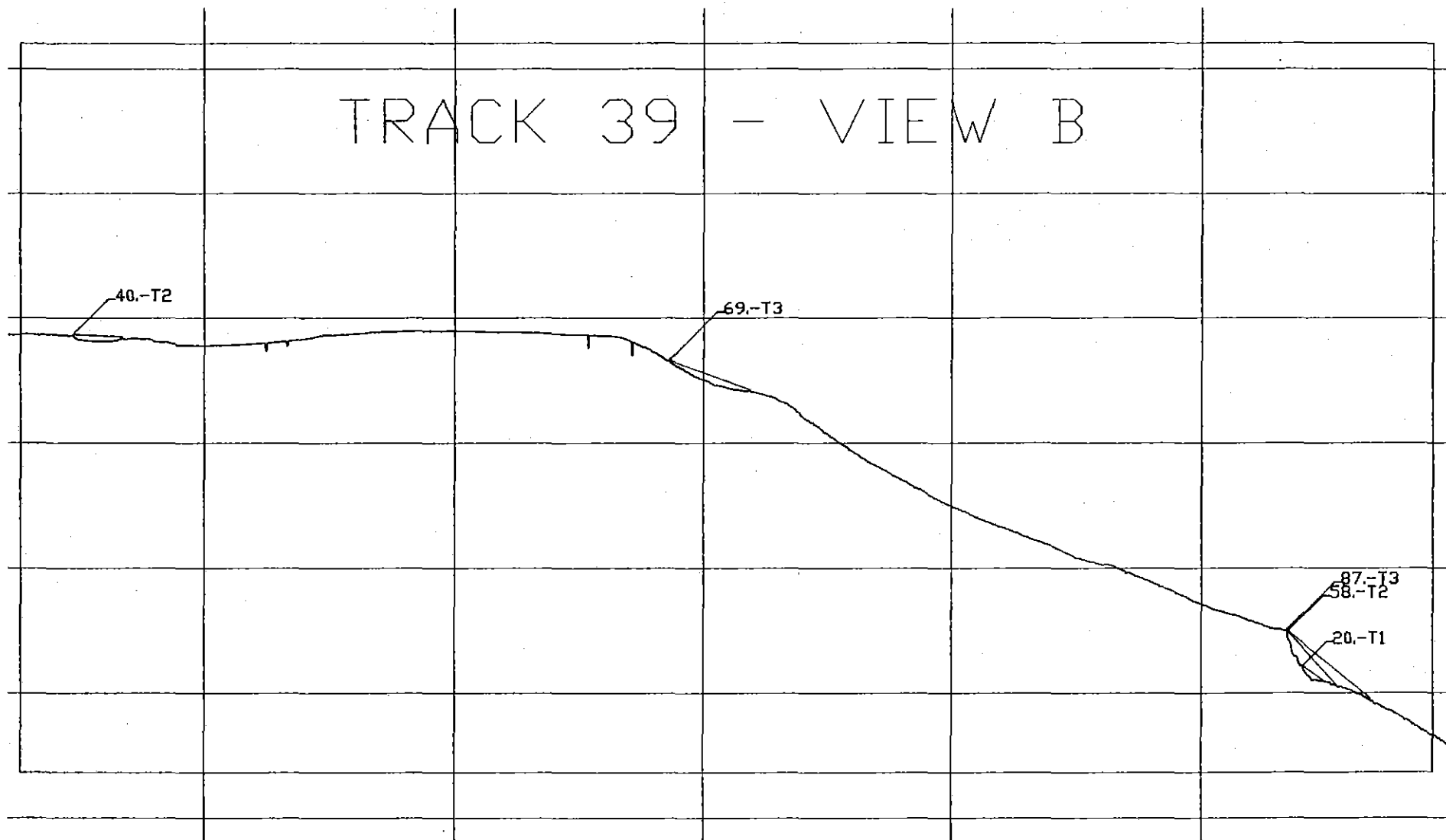


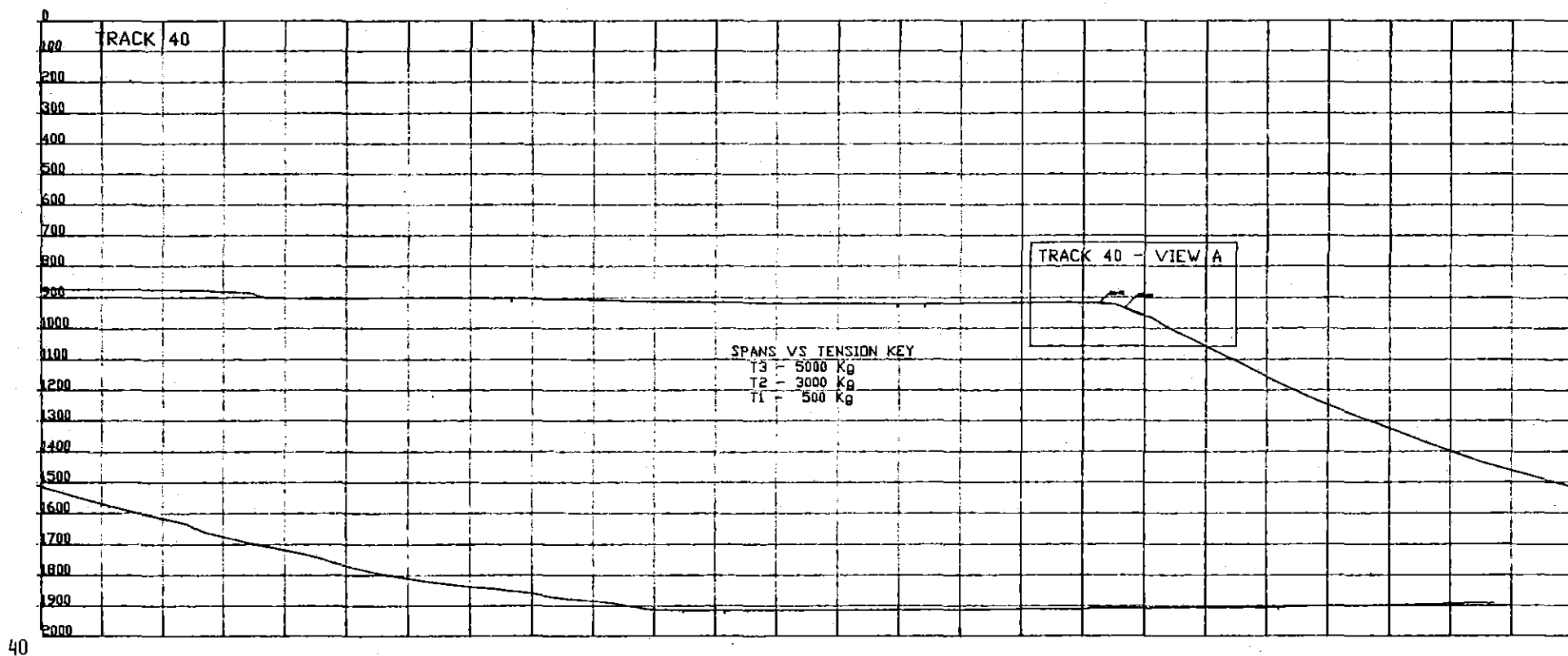
# TRACK 39 - VIEW A

71.-T3  
57.-T2

56.-T3  
42.-T2

# TRACK 39 - VIEW B





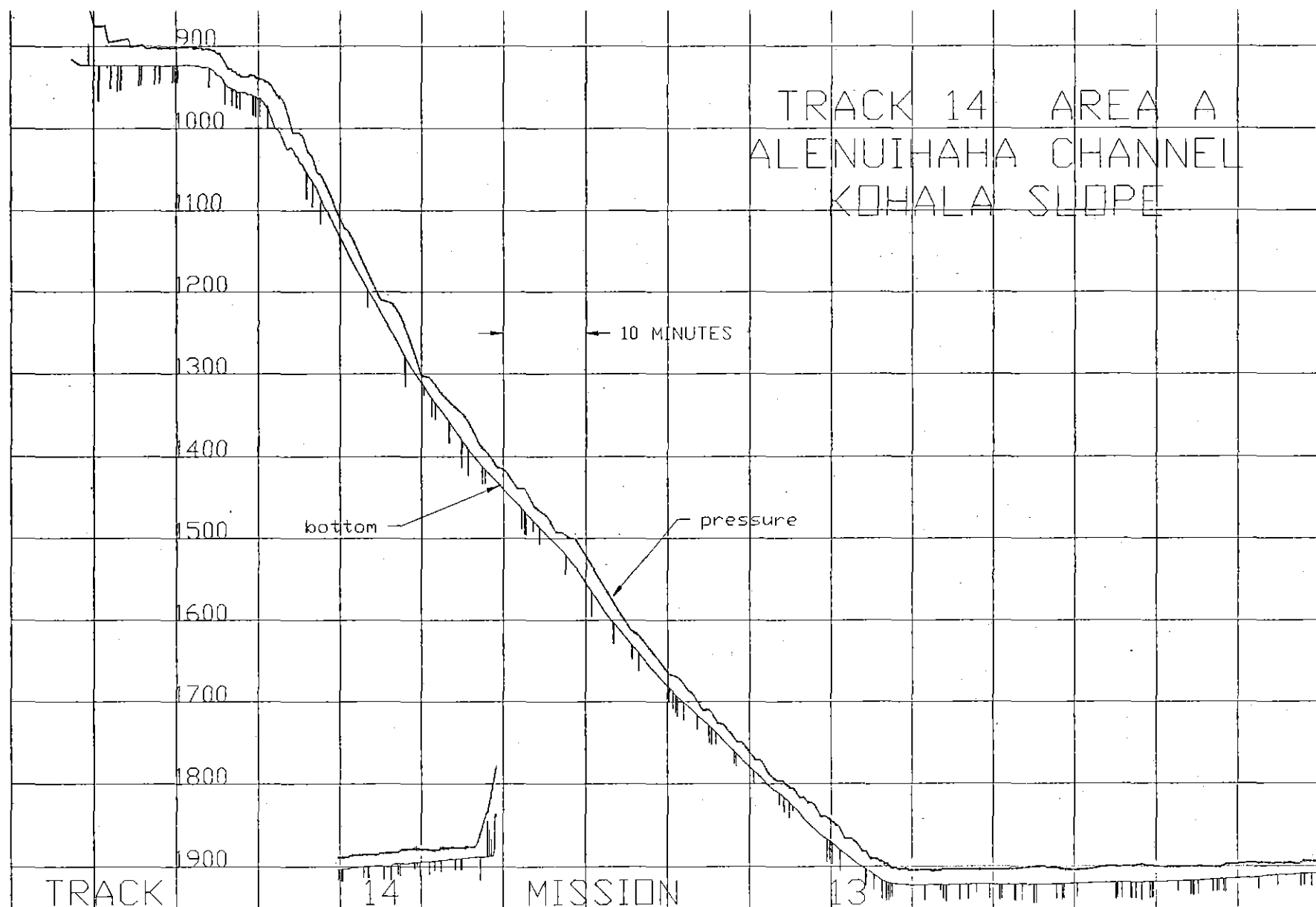
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38.-T2

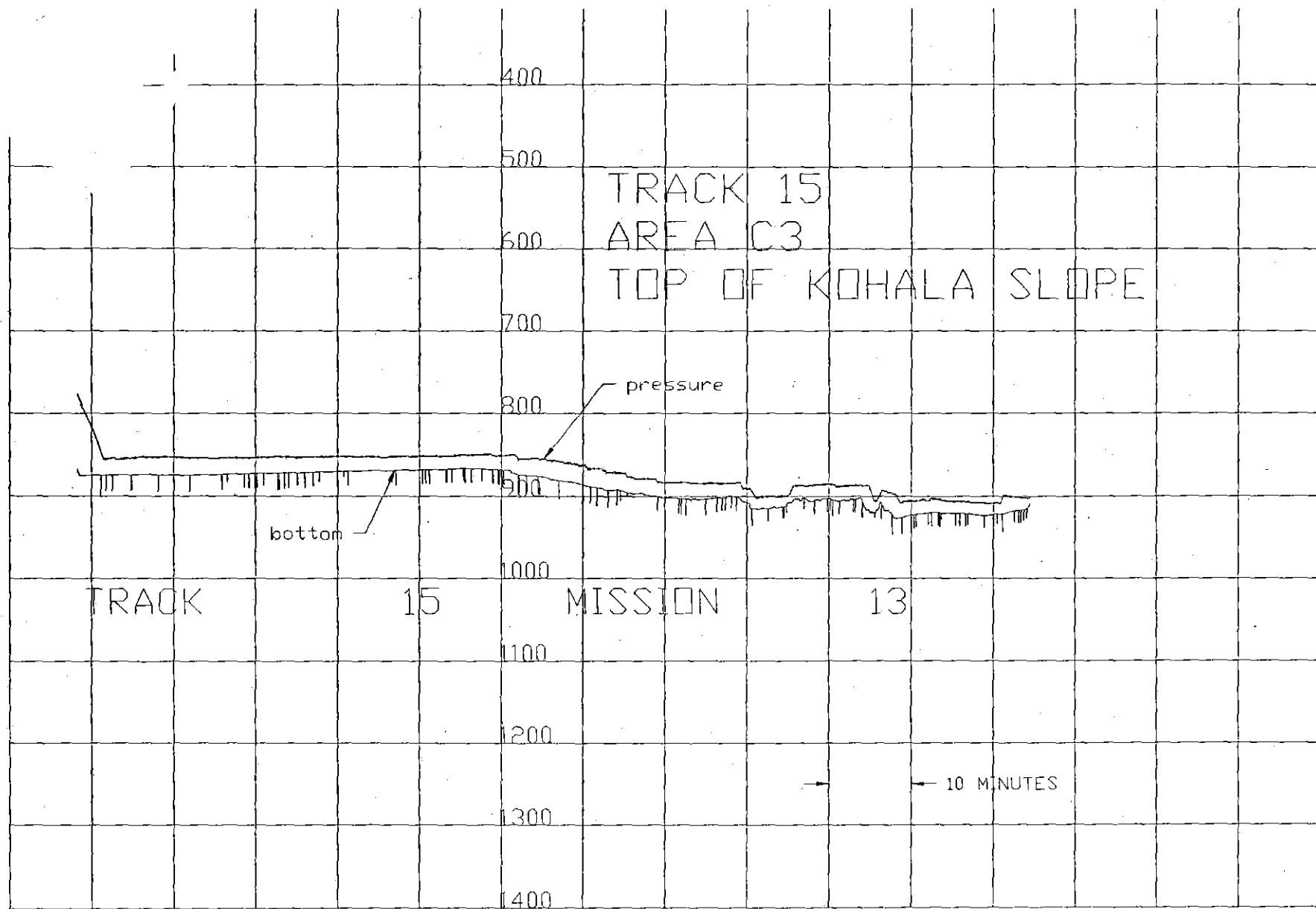
65.-T3

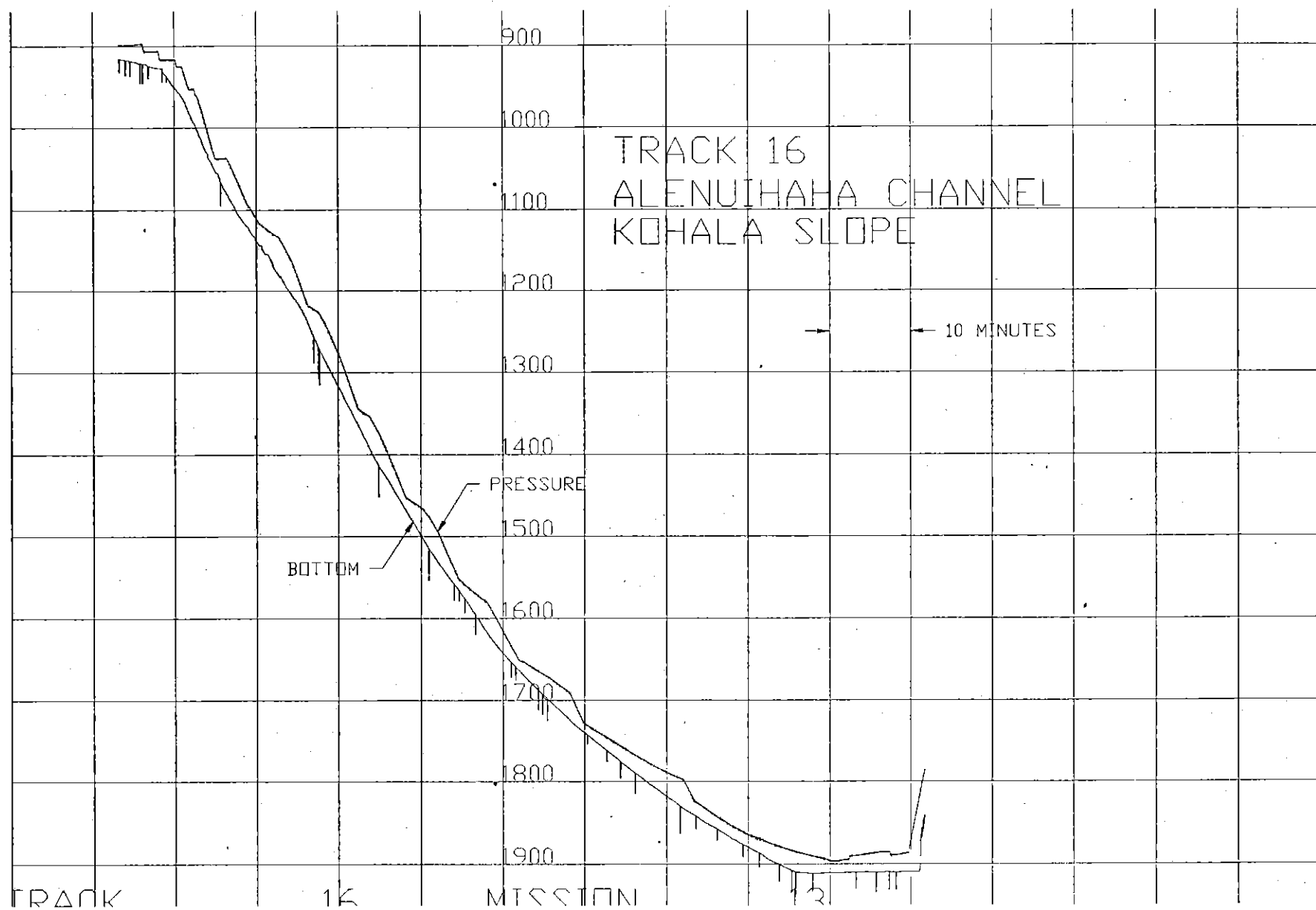


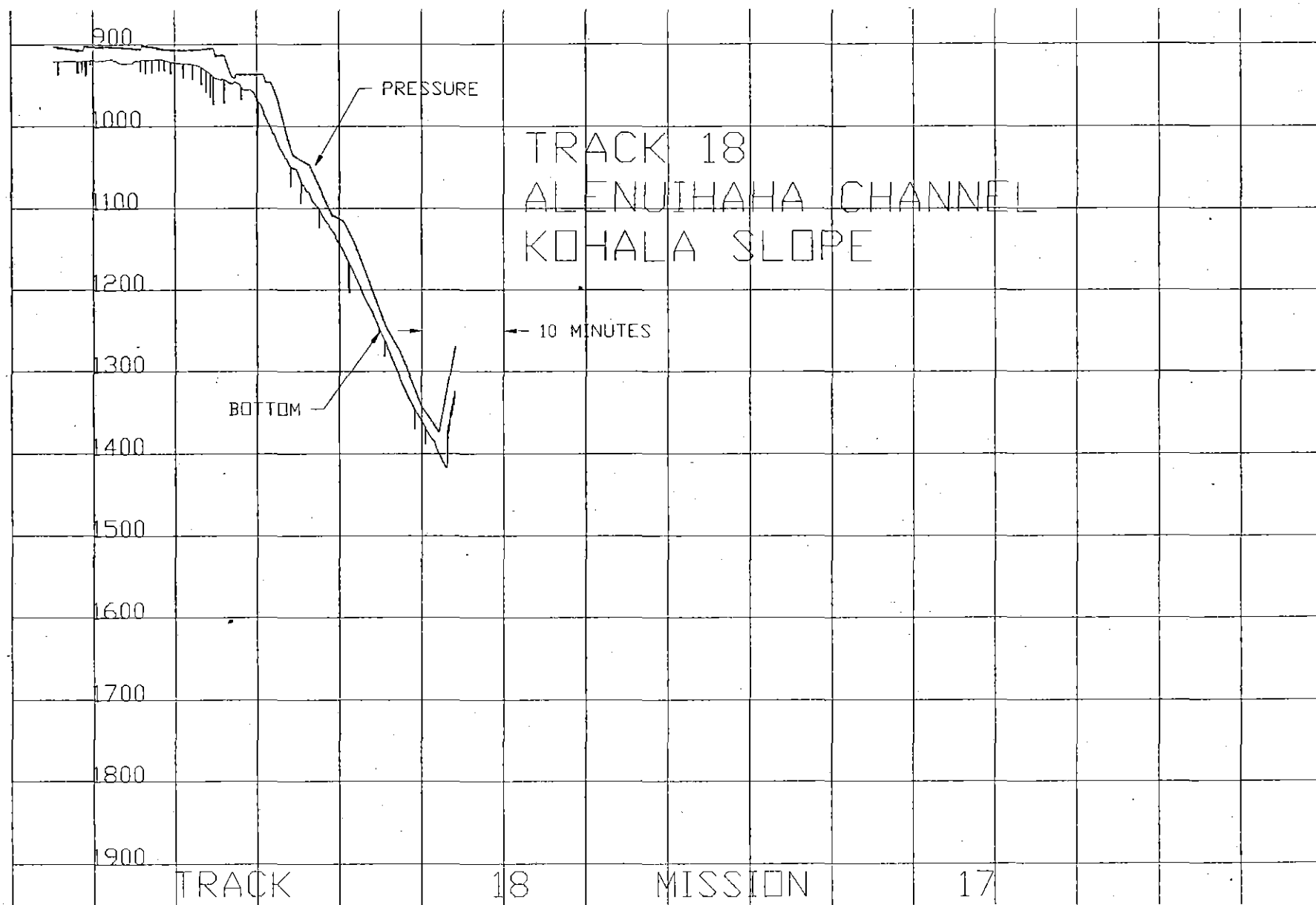
TRACK 14 AREA A  
ALENUIHAHA CHANNEL  
KOHALA SLOPE

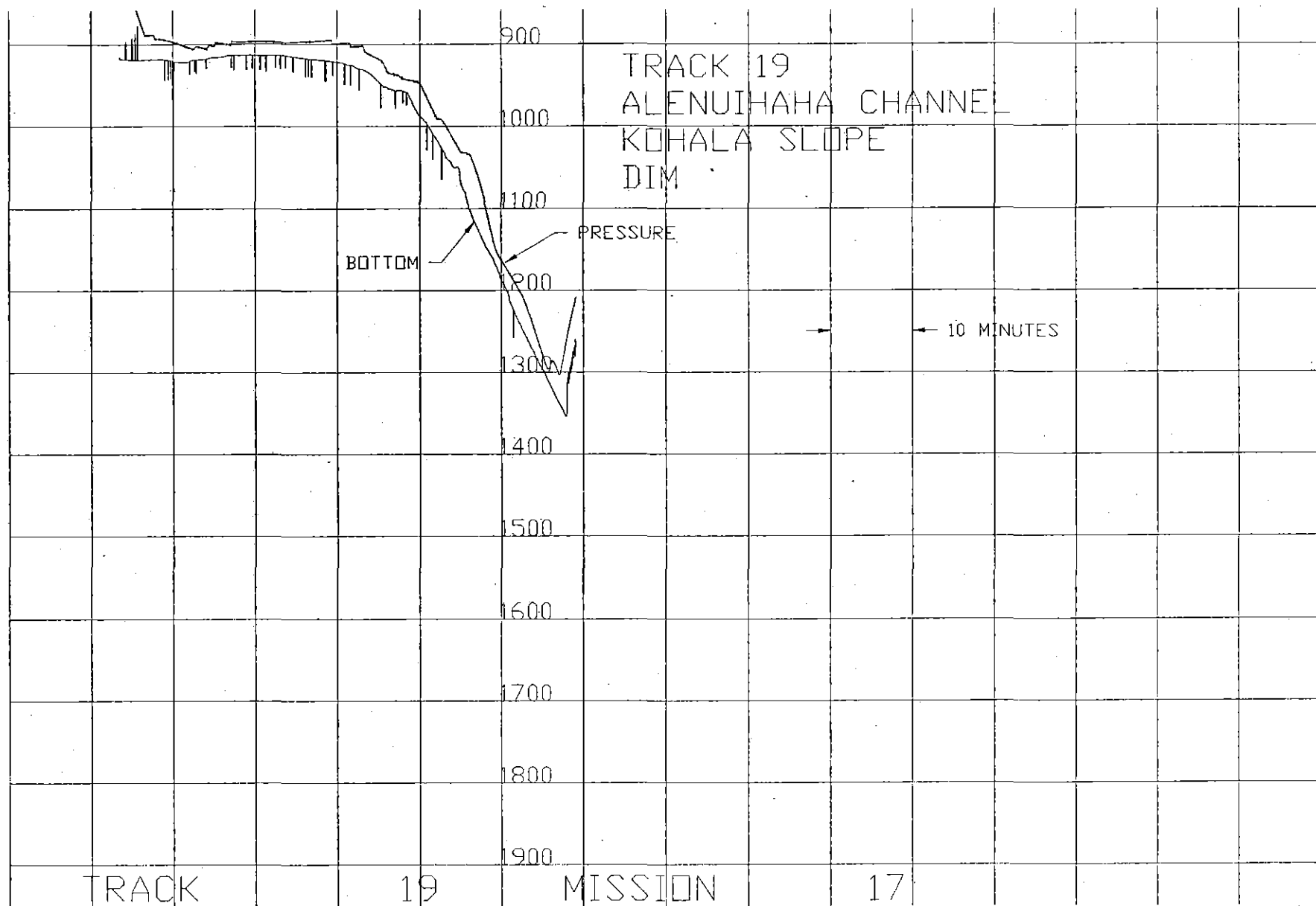


meters

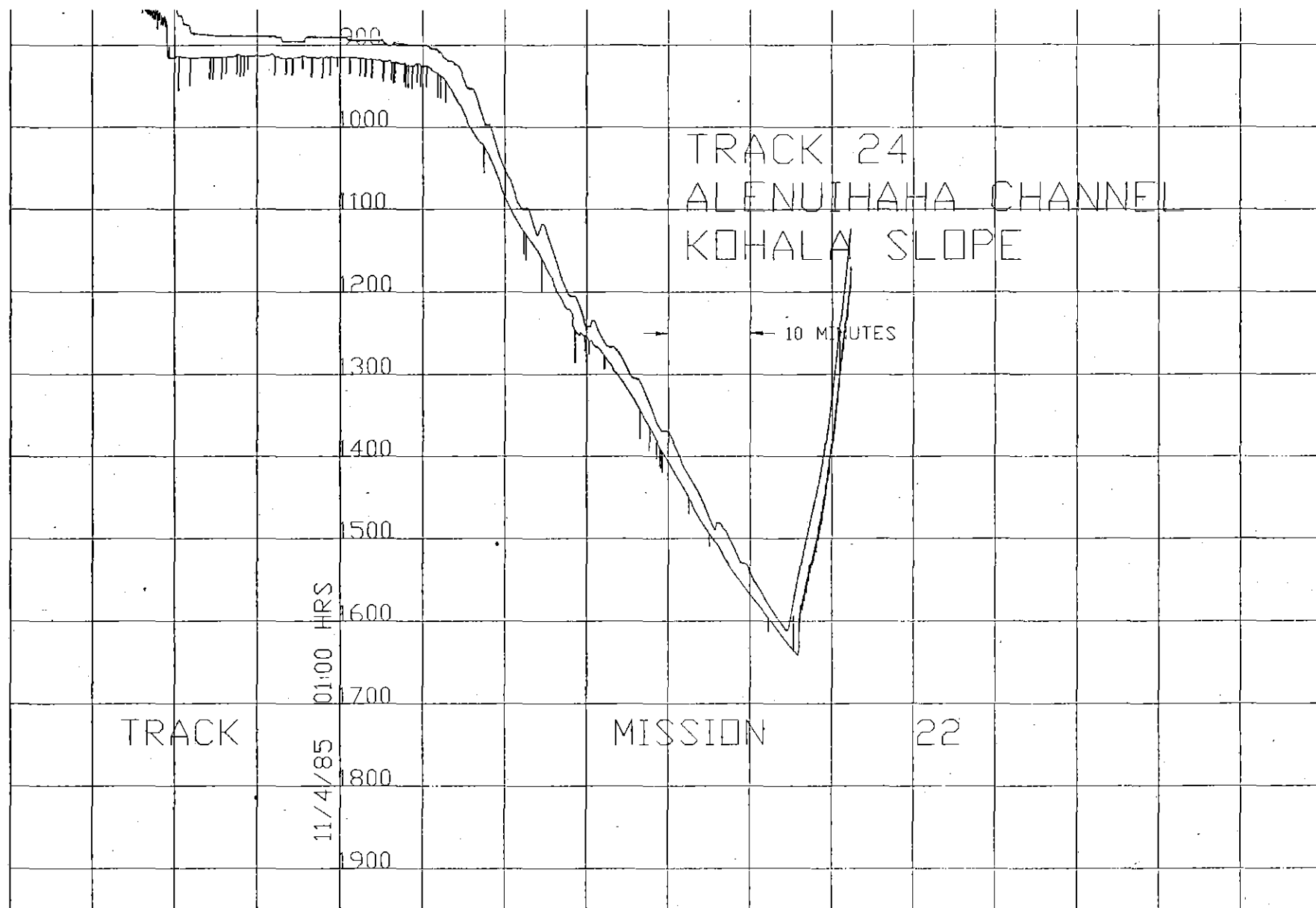


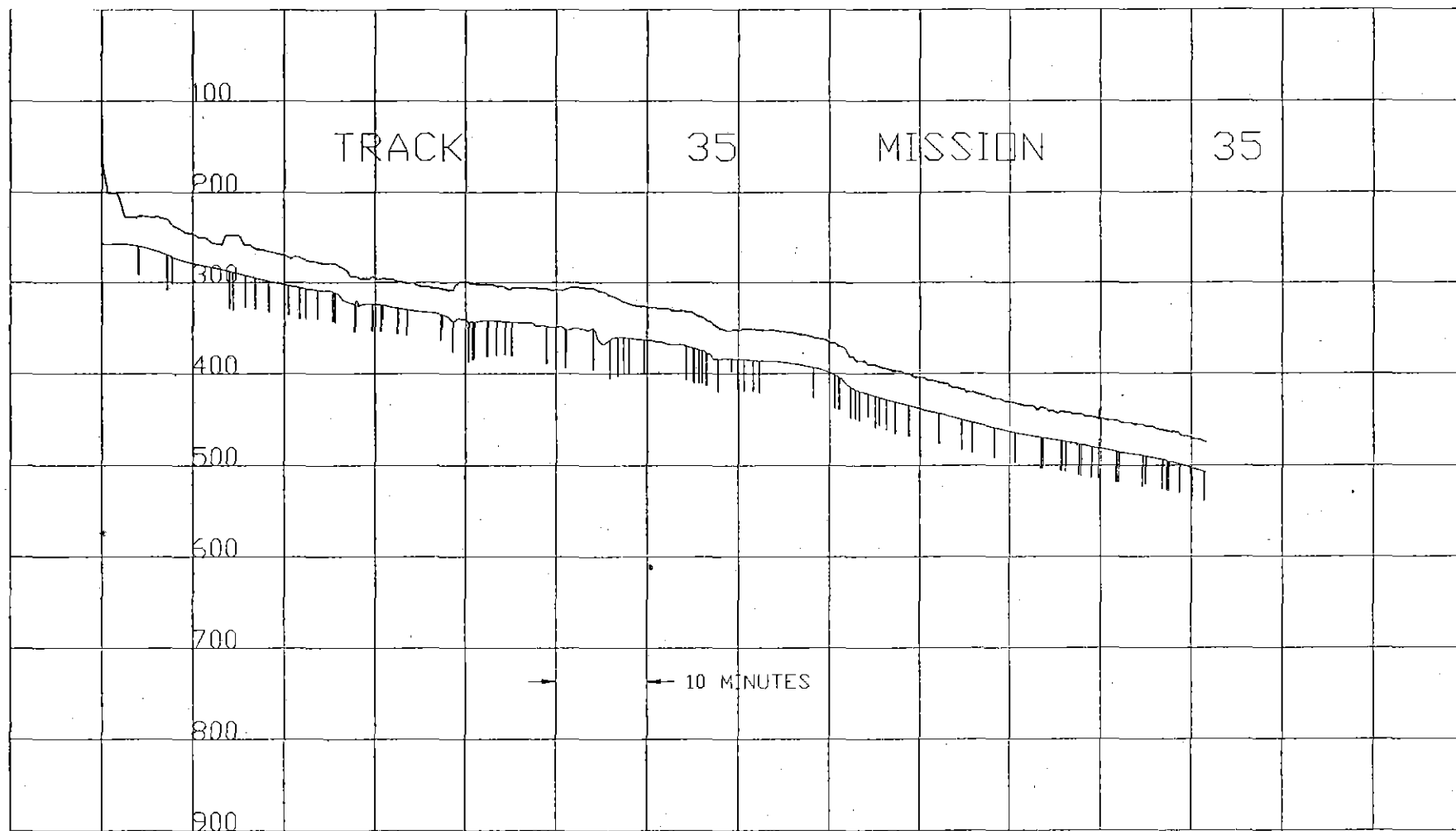






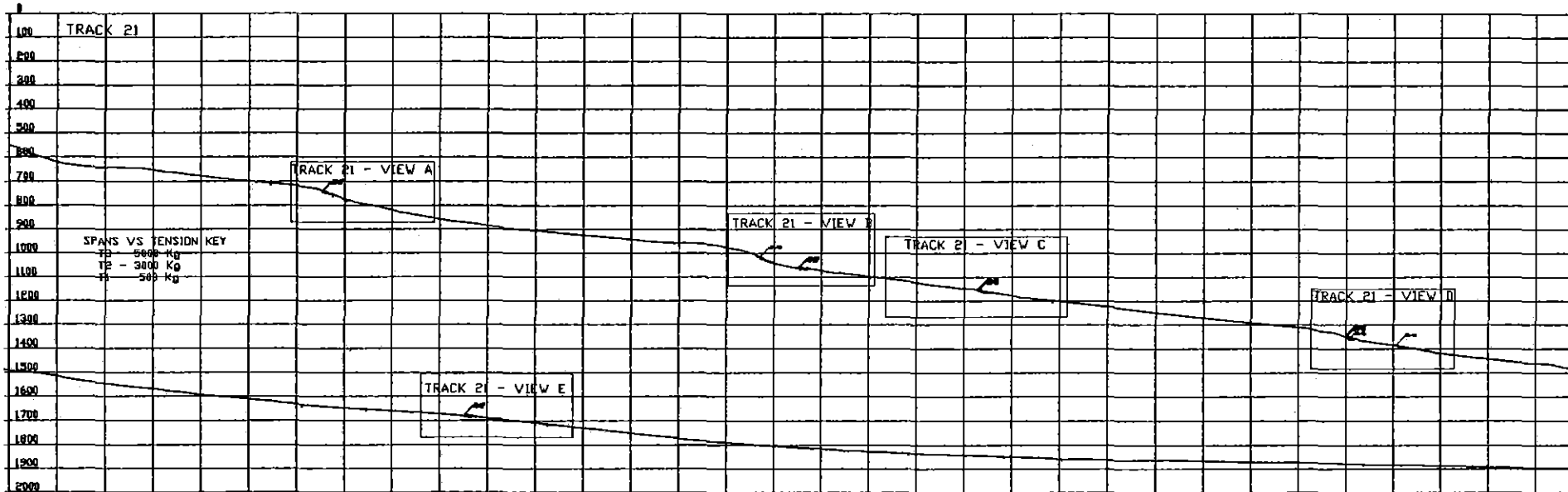
11/3/65  
G.F.M.





**APPENDIX B**  
**BRS PROFILES, MAUI SLOPE**

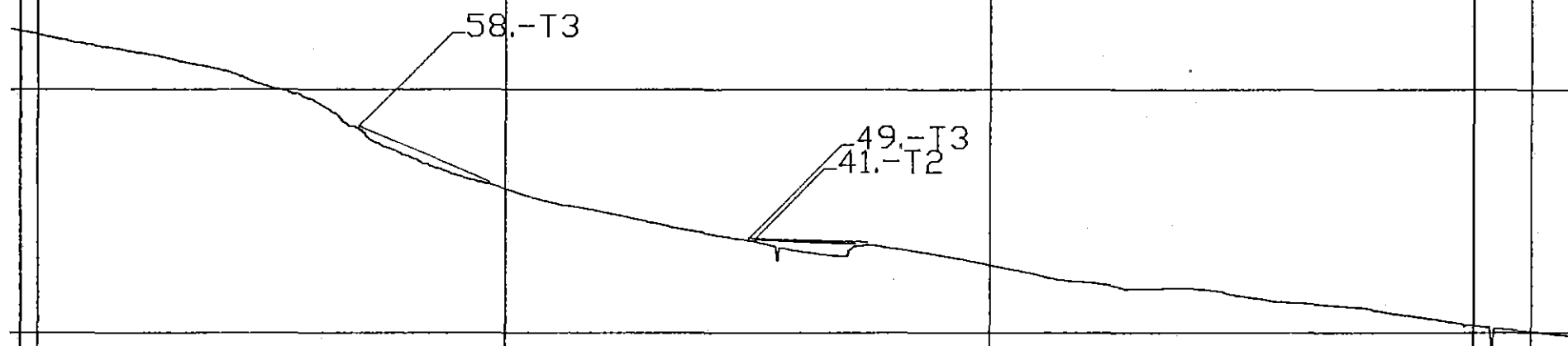




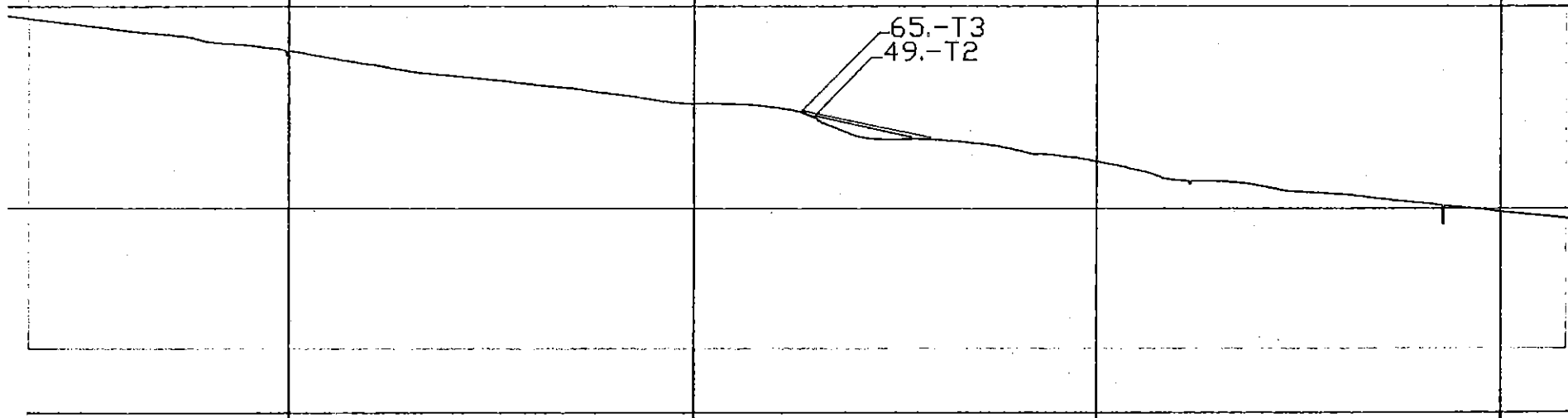
# TRACK 21 — VIEW A

55-T3  
42-T2

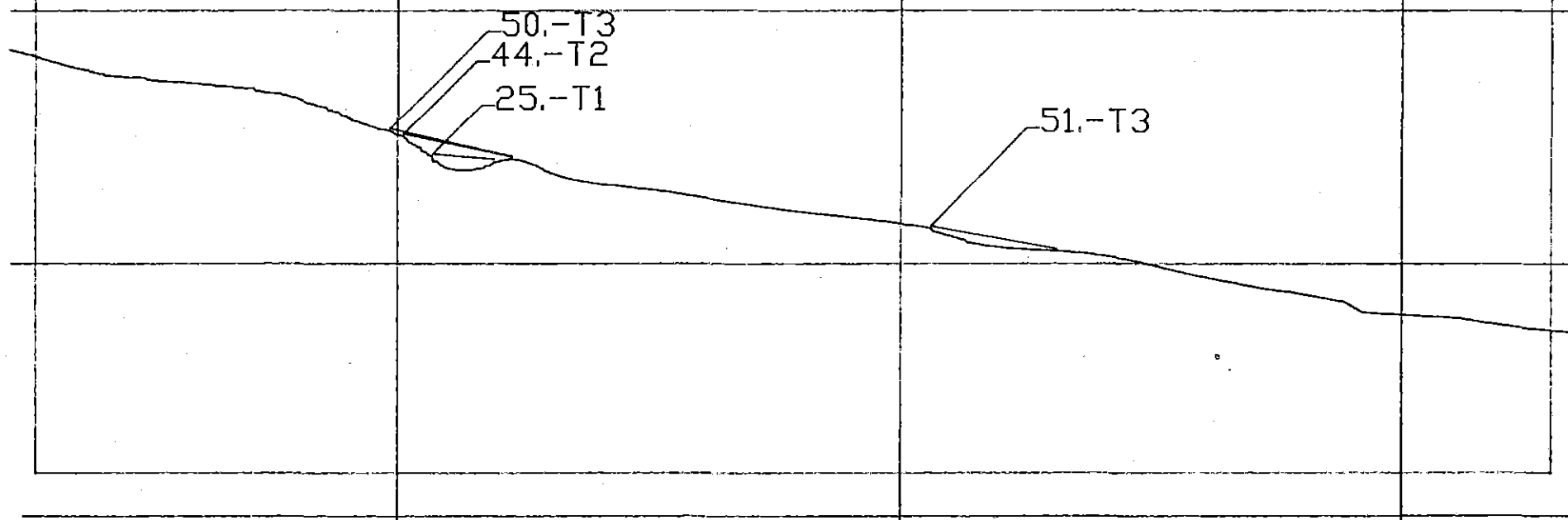
# TRACK 21 - VIEW B



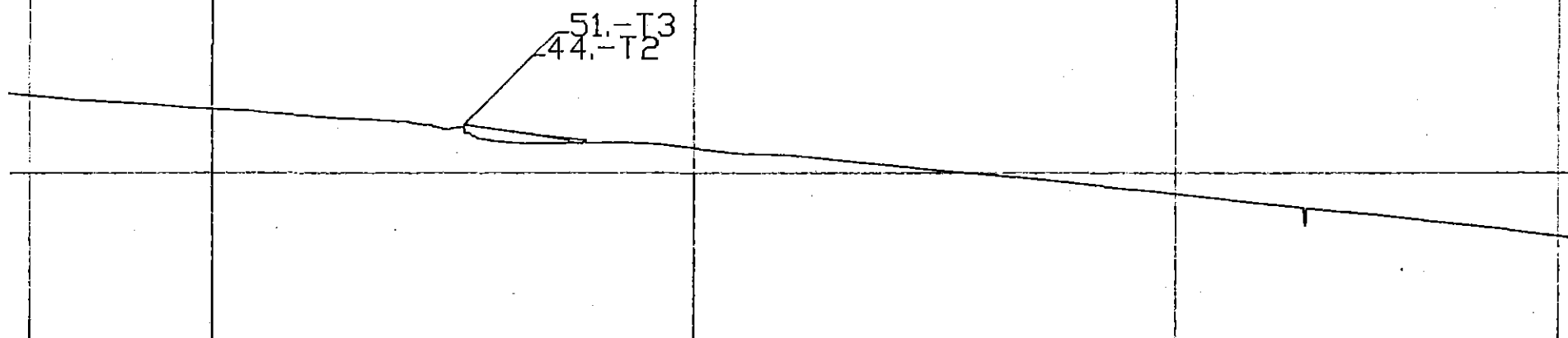
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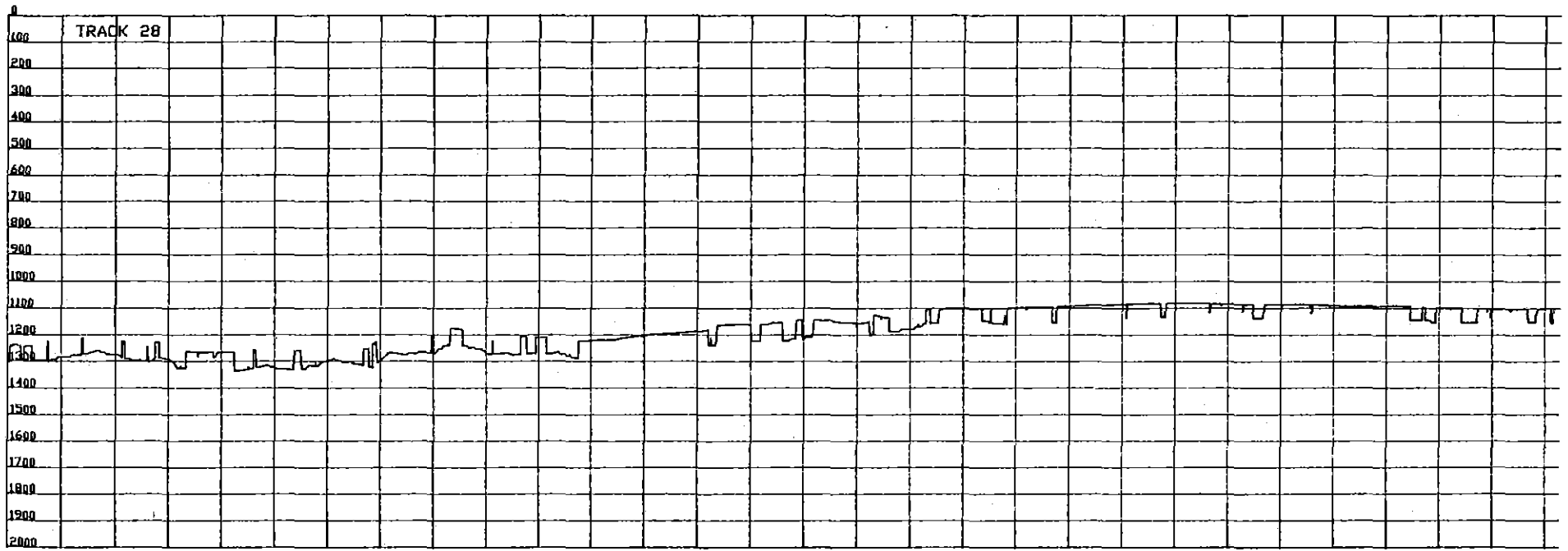


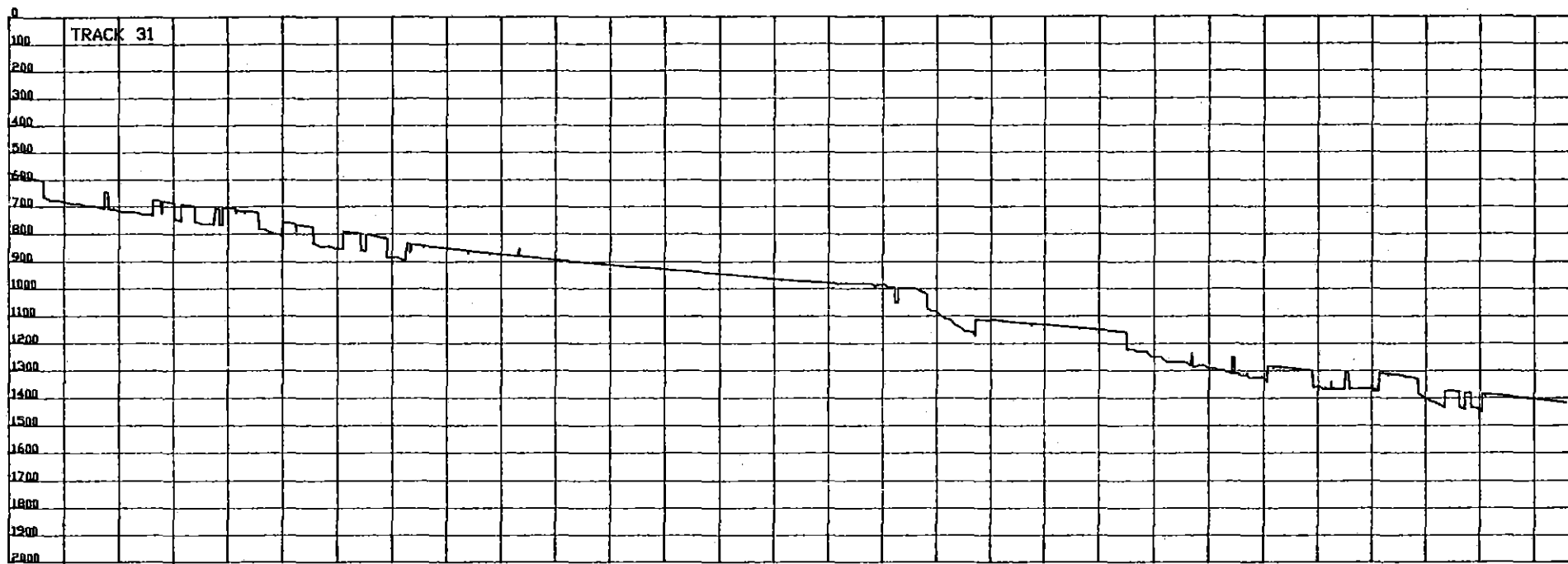
# TRACK 21 - VIEW D



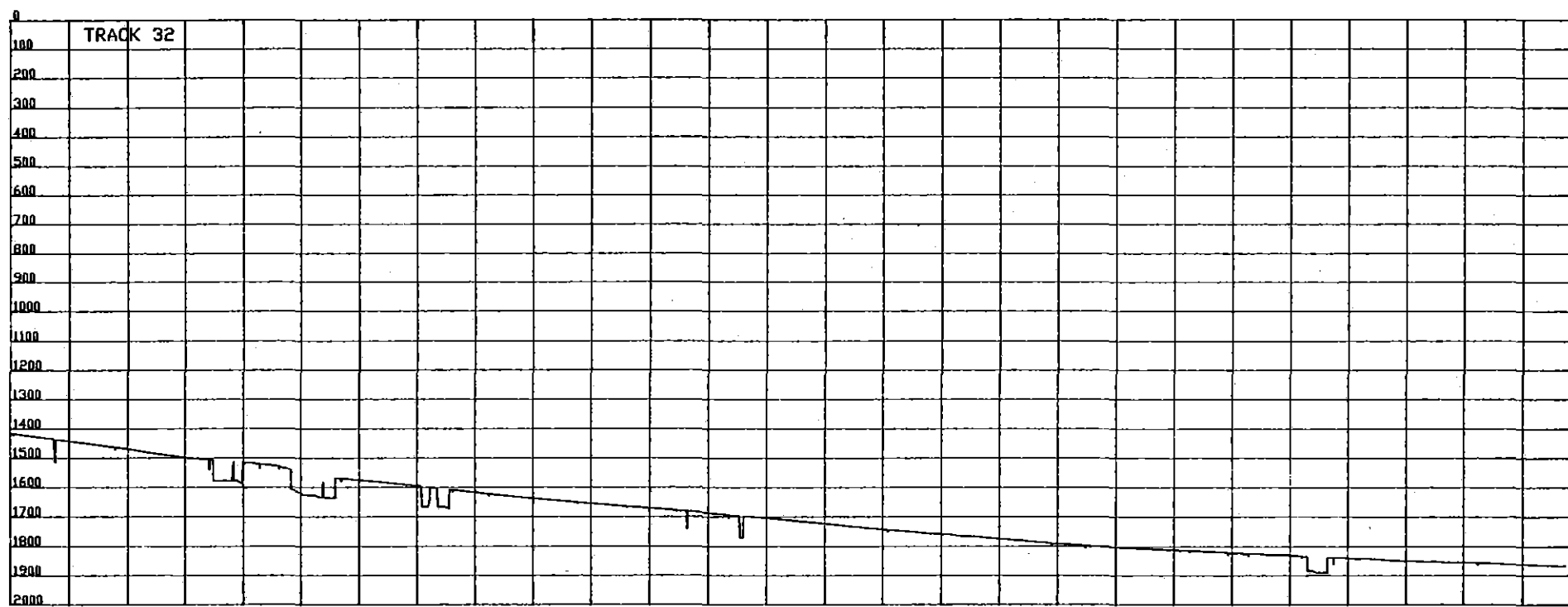
# TRACK 21 - VIEW E

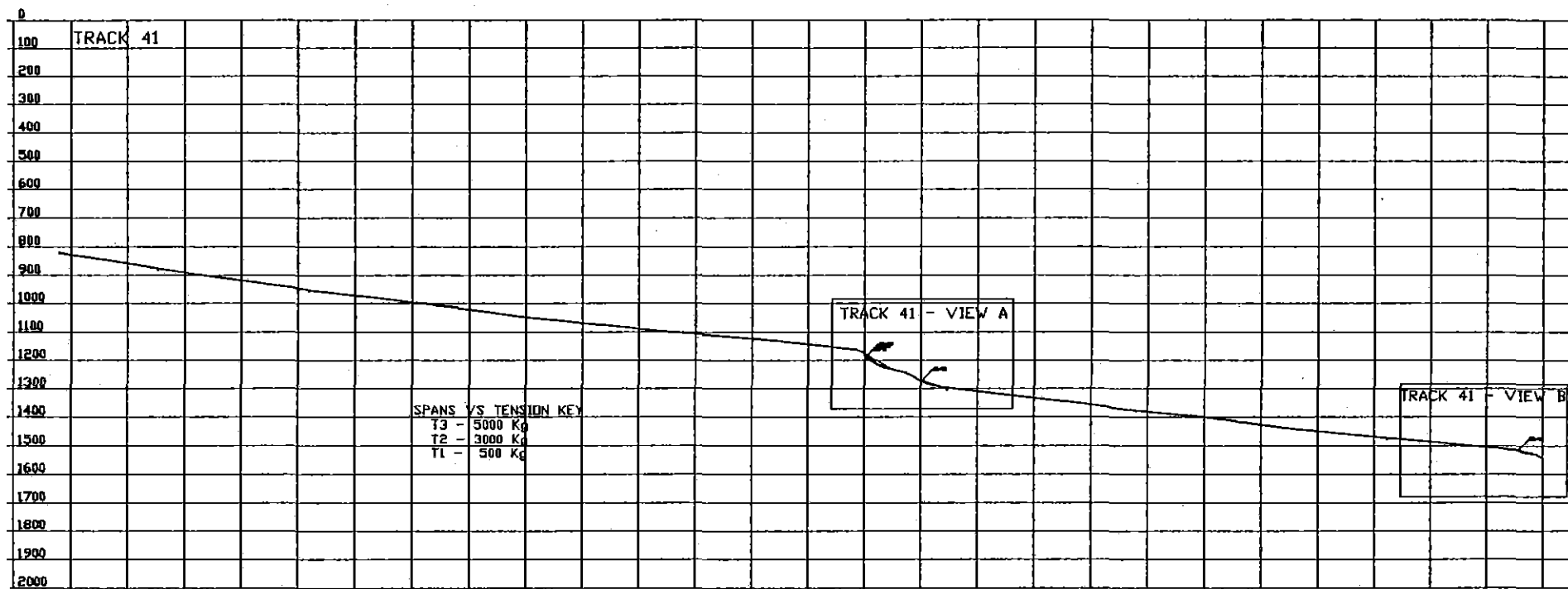




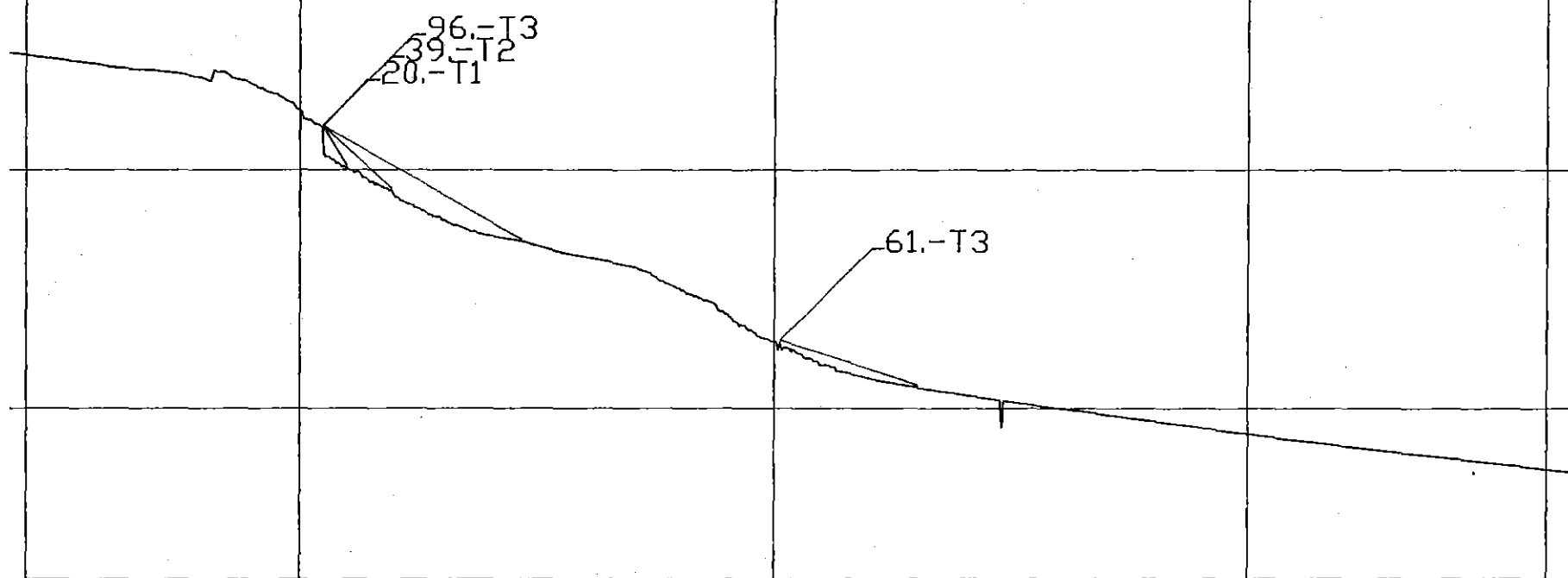






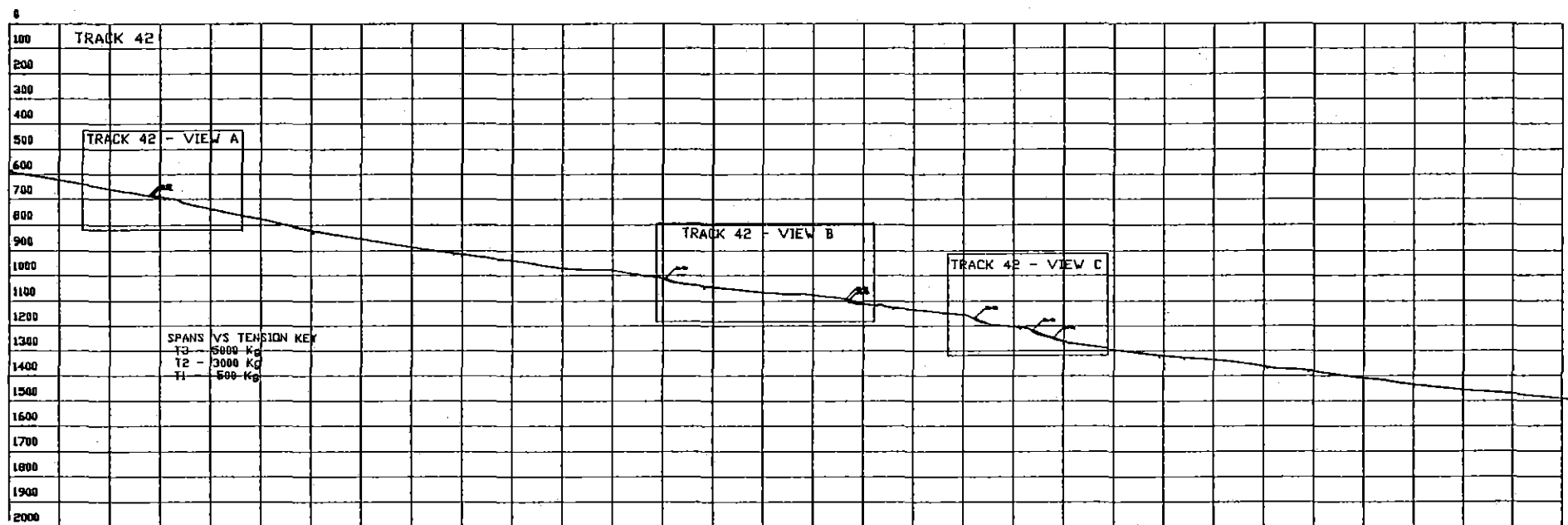


# TRACK 41 - VIEW A



# TRACK 41 - VIEW B

53.-T3



# TRACK 42 - VIEW A

49.-T3  
40.-T2

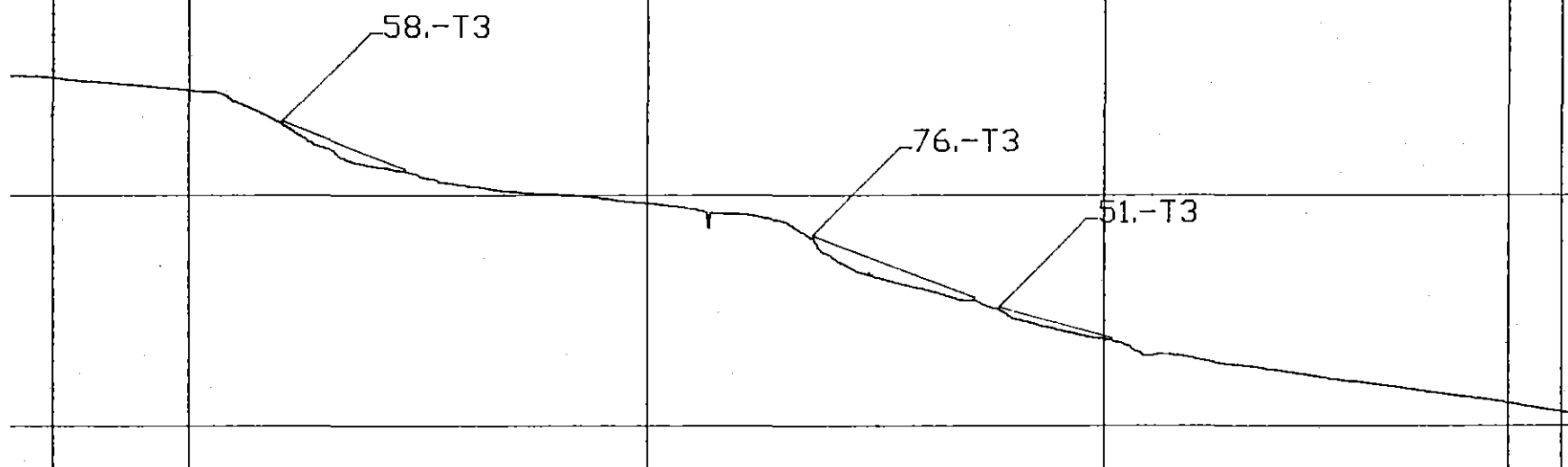
# TRACK 42 - VIEW B

50.-T3

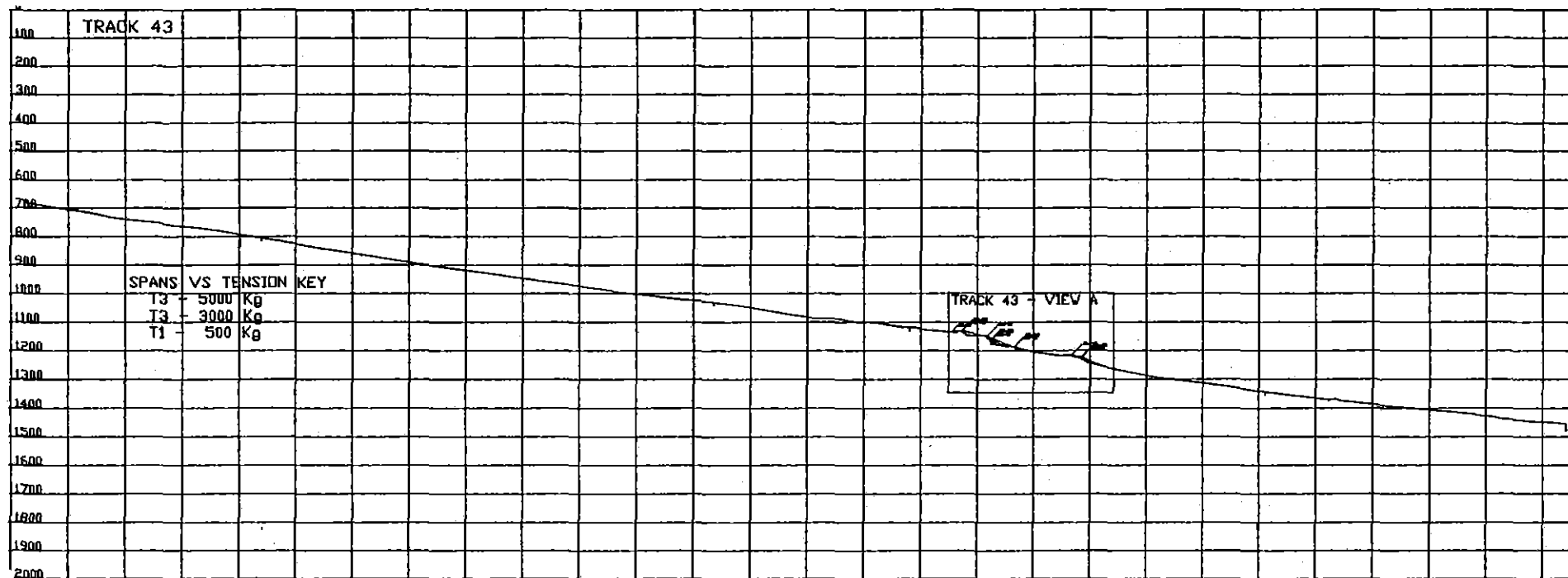
84.-T3

56.-T2

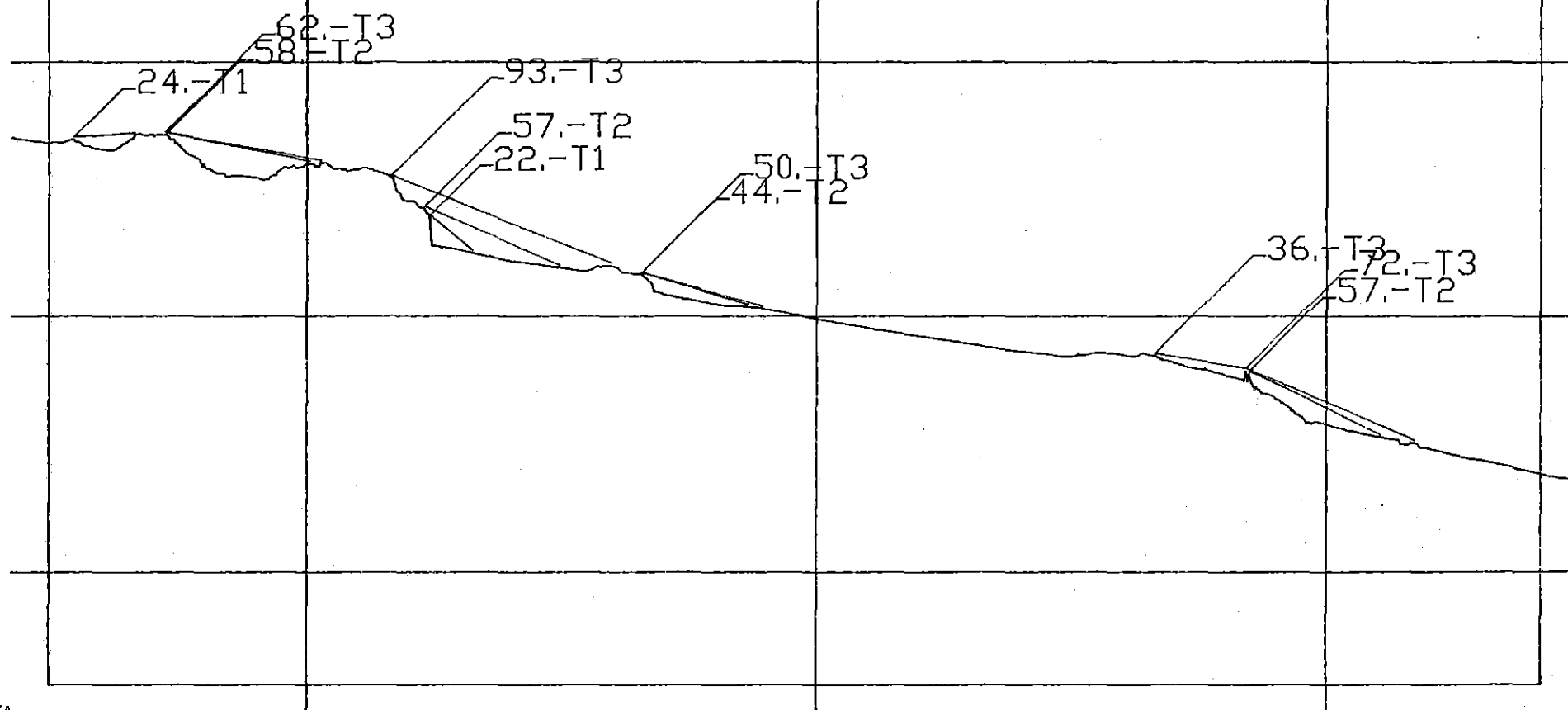
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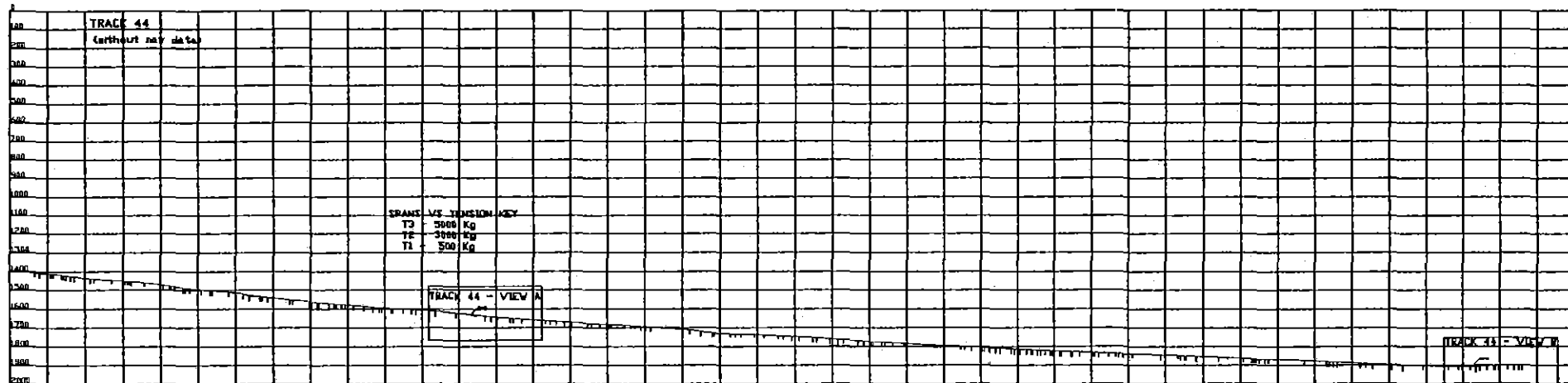




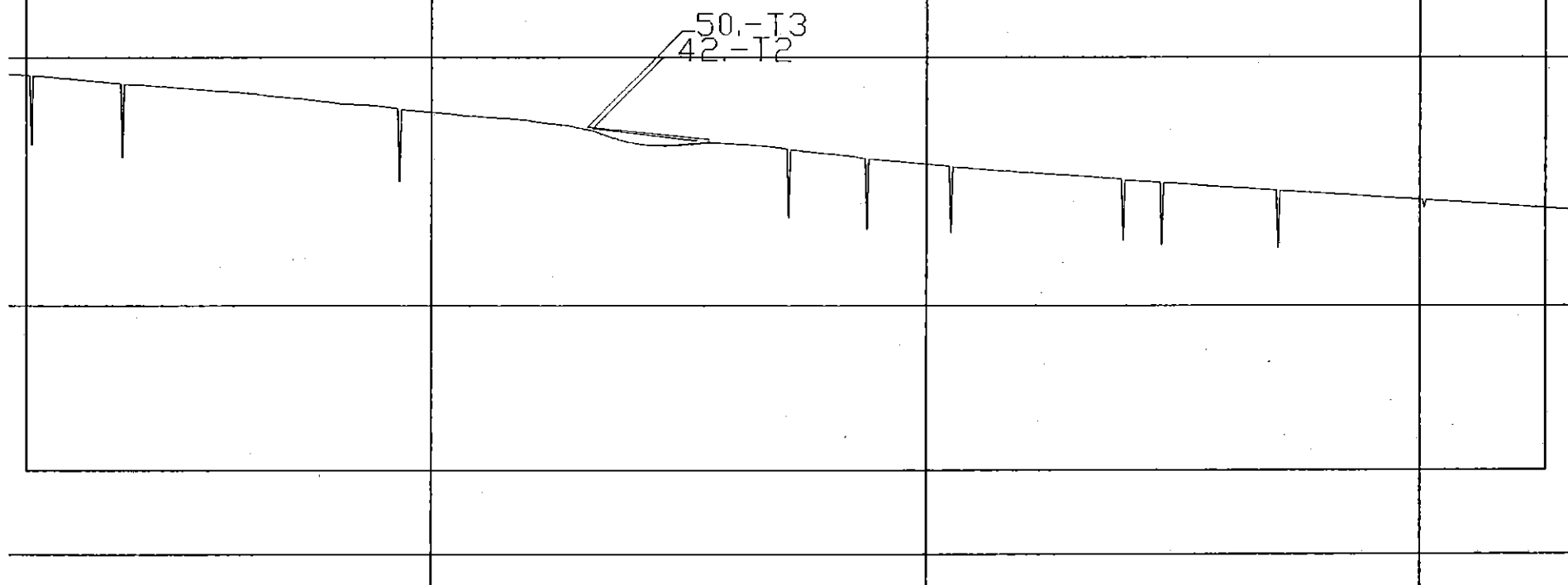


# TRACK 43 - VIEW A



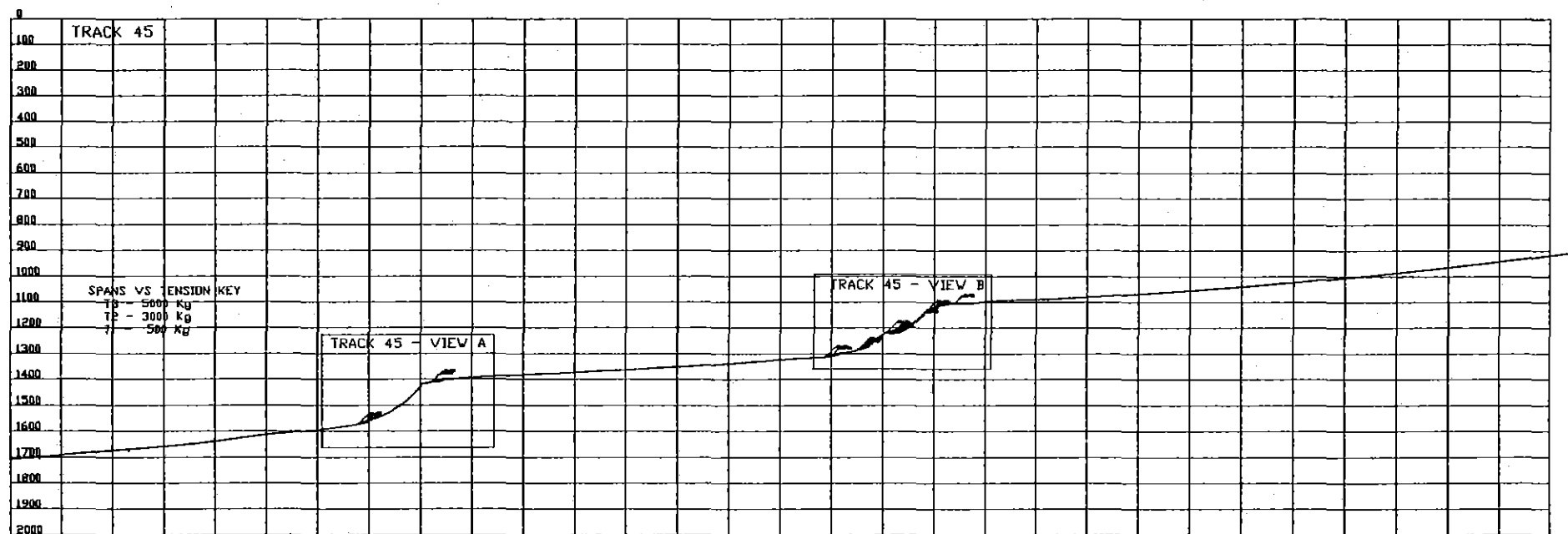


# TRACK 44 - VIEW A



# TRACK 44 - VIEW B

54.-T3



TRACK 45 -

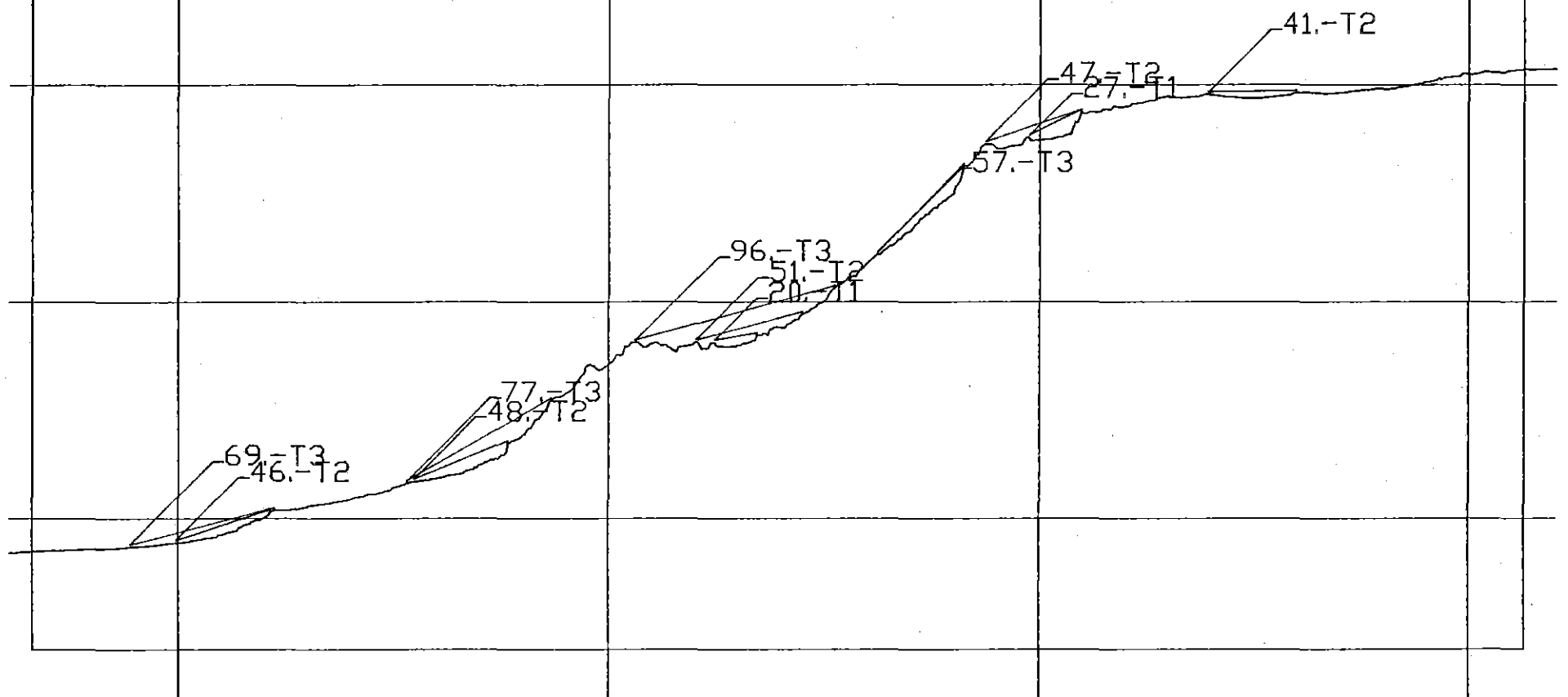
VIEW

A

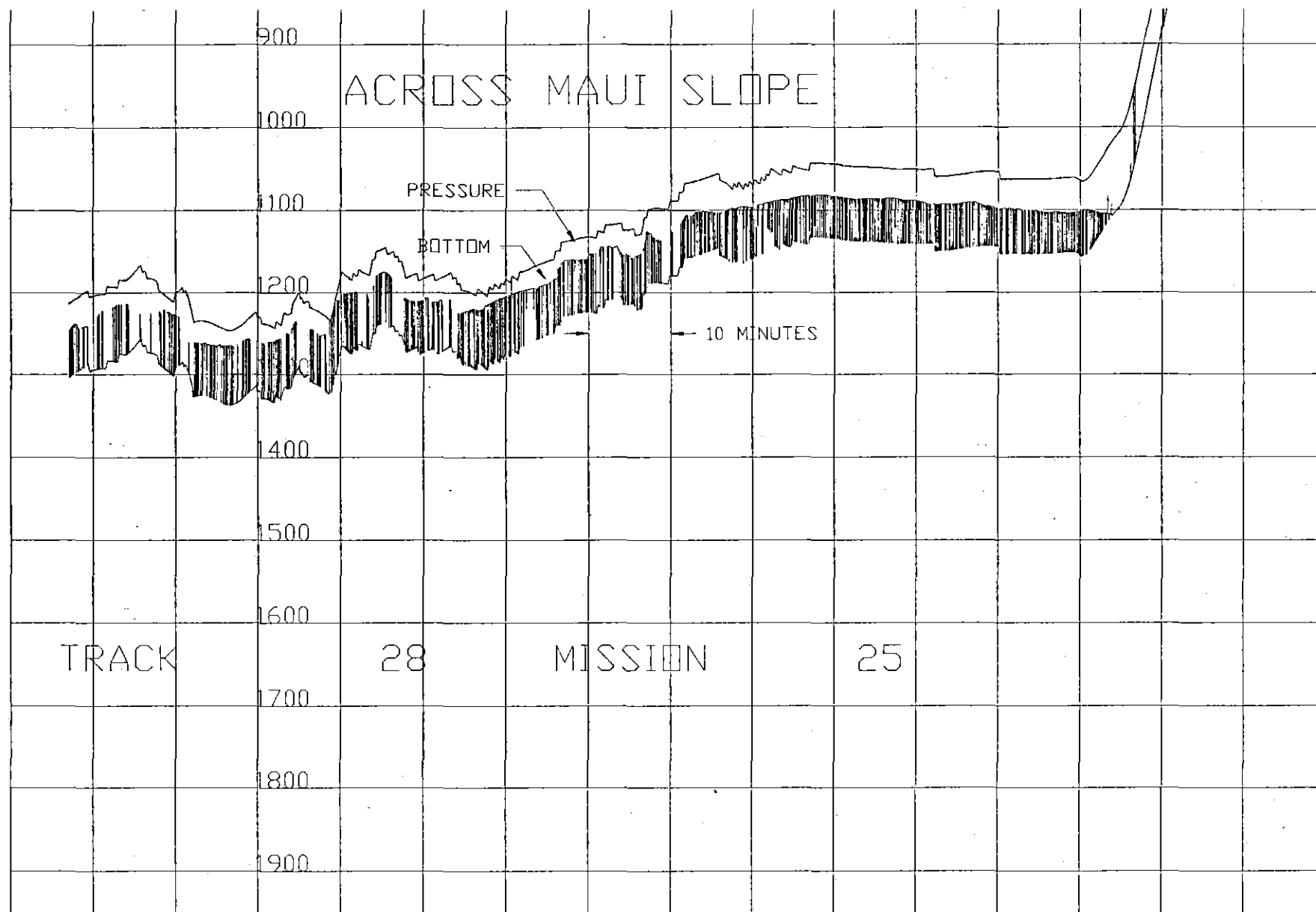
61.-I3  
41.-T2

49.-I3  
42.-T2

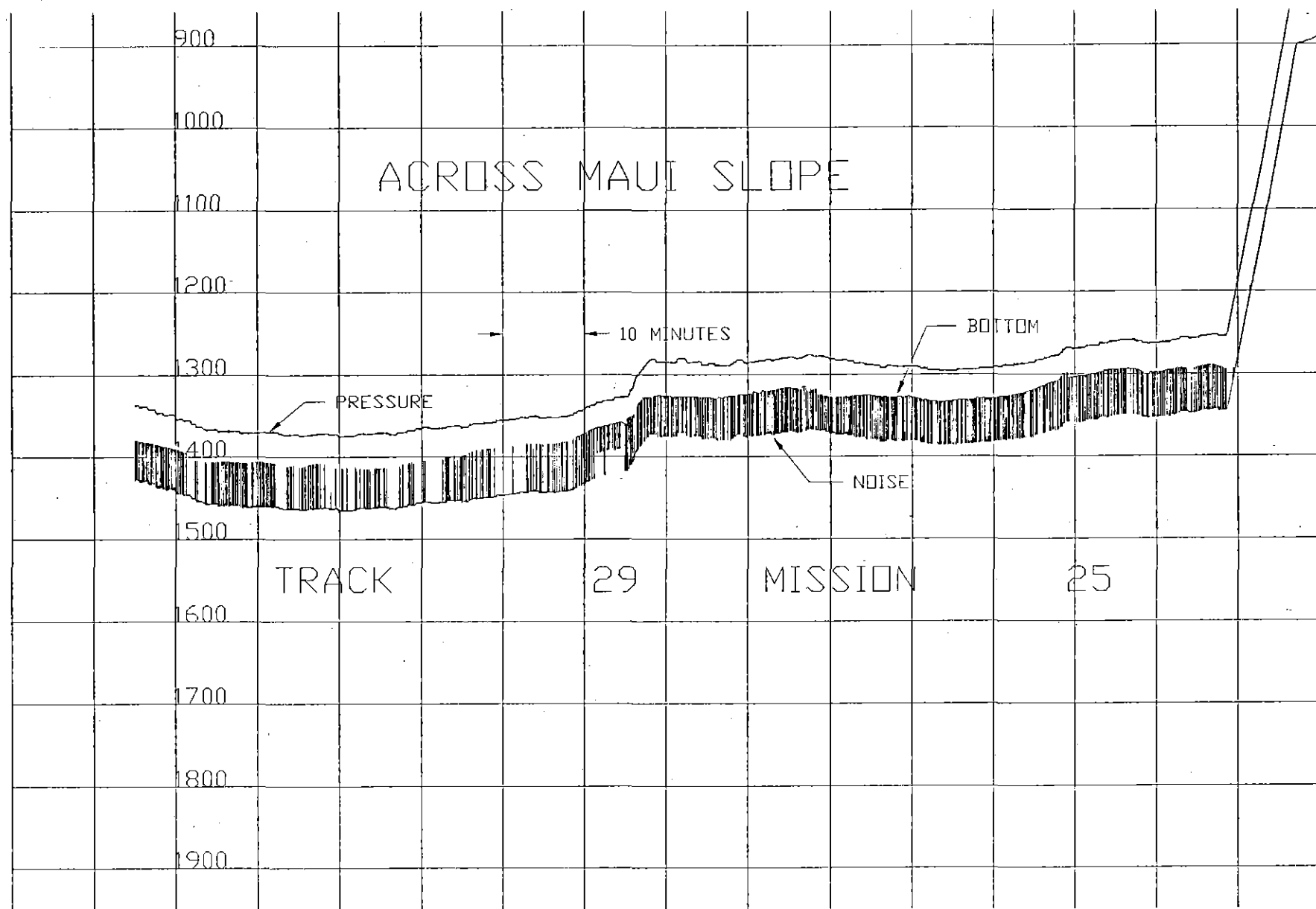
# TRACK 45 - VIEW B



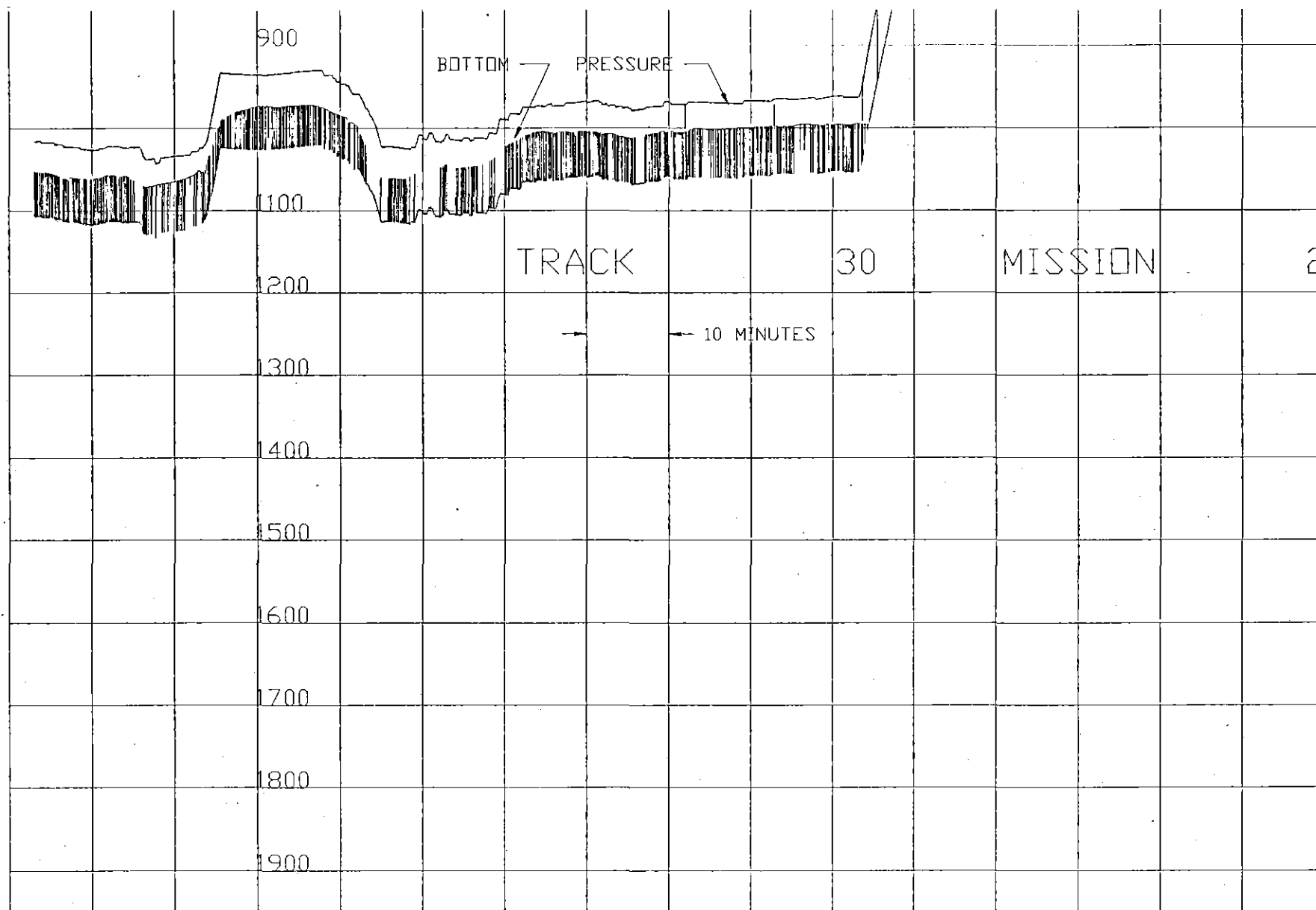




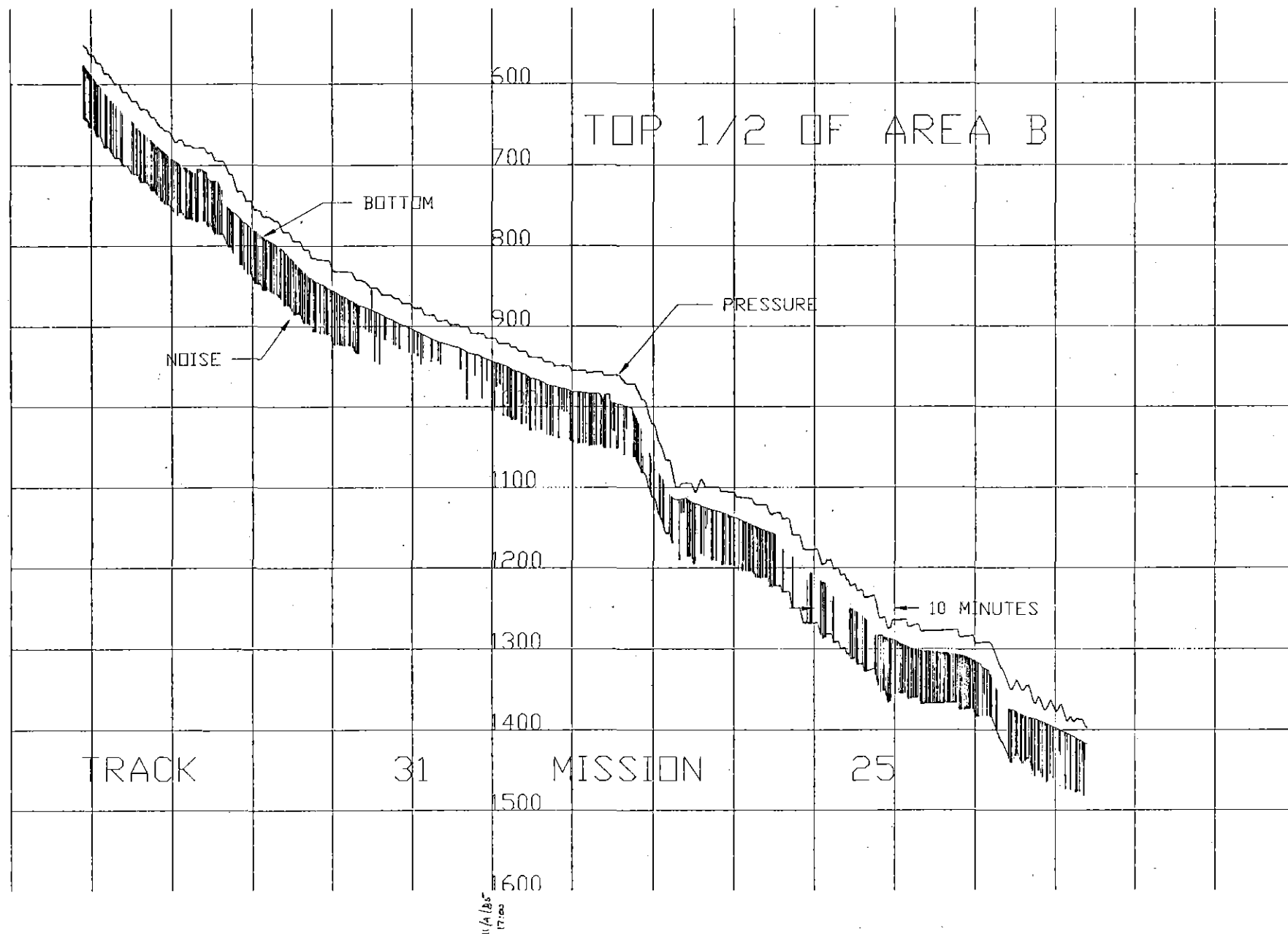
41.65  
07:00

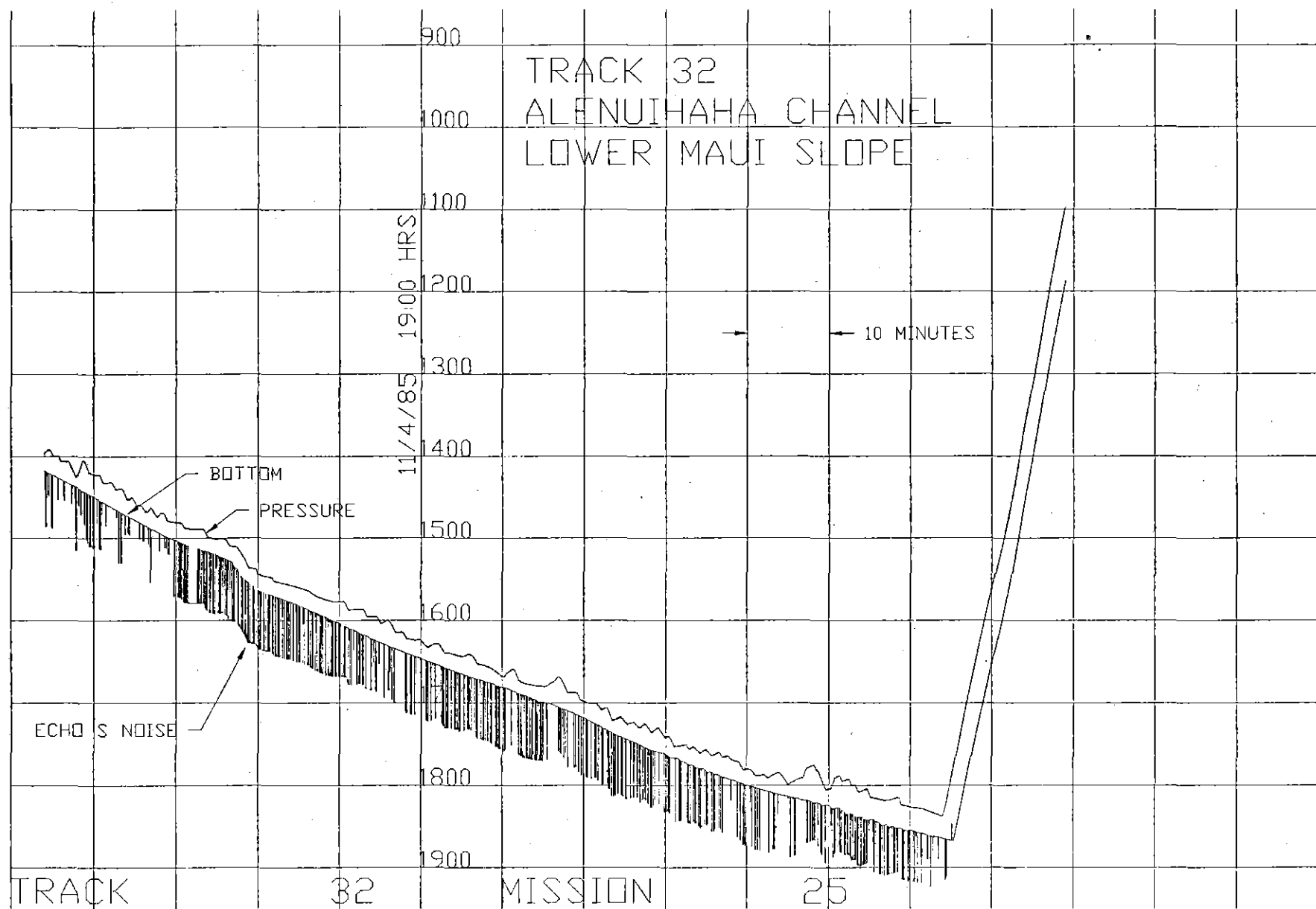


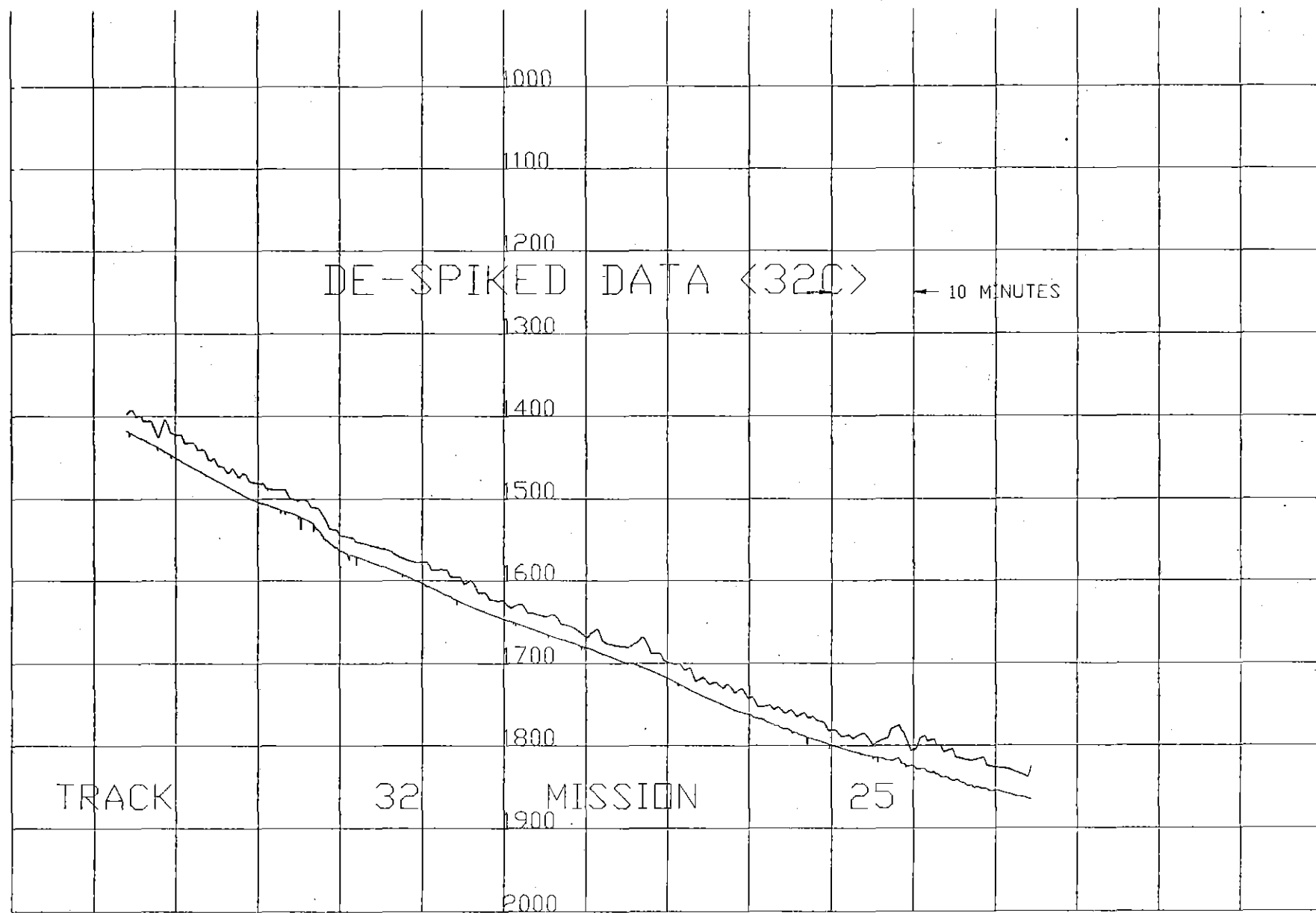
10.00  
4/11/85



U/135  
14:00







APPENDIX C

CRUISE LOG

Oct 29-Nov 5, 1985

HDWC BOTTOM ROUGHNESS SURVEY LOG

MOANA WAVE

10/29/85

- 15:30 meet ship in Kawaihae. Start installing transponder under ship.
- 18:00 Dunk test in harbor of echo sounder and pressure gauge. Test is successful.
- 19:00 U/W navigation transponder interrogator installed under ship. Depart Kawaihae.
- 21:00 Fire and abandon ship drills. General scientific crew meeting to review mission, duties, etc.
- 23:00 Start deployment of transponders.

10/30/85

- 03:30 Transponders installed.
- 04:00 Interrogator on hull not effective, cannot "talk" to bottom transponders. Tow fish interrogator deployed.
- 04:30 Surveying of net (boxing in two bottom transponders positions) started.
- 06:00 Sippican disposable sound velocity measurement probes deployed. Takes several attempts, finally get one to take. Break wires on ship hull. 4 attempts total.
- 11:00 Circle fixes around two primary deep corner transponders, radius 4 km. After second circle, data lost due to operator error - position established manually with printed data. Start establishing all distances between bottom transponders to finally establish grid.
- 16:00 BRS in water for mission 1, track 1, (across top of Kohala slope, 1000 m). No bottom Nav, cannot get BRS transponder to respond.
- 18:45 Track 2 started, continuation of track 1, turn and go down hill.
- 19:00 Transponder interrogator fish lines cut by BRS cable
- 21:15 End of mission 1 and BRS returned to deck, interrogator fish is snagged on BRS cable and is recovered.
- 22:00 Bad echo sounder detected through data analysis, replaced with back up, tracks 1 and 2 a loss. Pressure traces look good but some spikes in signal.

10/31/85

- 02:30 Start of mission 3, track 3, down Kohala slope
- 03:00 Transponder on BRS not functioning.
- 06:15 End of track 3, mission 3 - BRS returned to ship.
- 07:15 Satisfactory elevation data from mission 3 plotted vs time, position being processed from ship position; jumps in pressure gauge gone through input power filtering.
- 08:30 BRS deployed for mission 4.



09:00 Transponder on BRS not functioning.  
 12:04 BRS returned to vessel  
 # Two range stations on Maui not responding well. Noda calls Maui man, will check in PM.  
 13:38 BRS Deployed for mission 5: Transponder mounted on wire, above steel frame. Several false starts, foul fish in wire again but comes free easily, come around again for another start. Transponders not working, decide we want top navigation only - try to improve bottom transponders as we go.  
 1745 Signal #2 transponder to come back: to replace one on BRS  
 18:00 End of track 5  
 18:30 Sight, lose, resight and recover transponder  
 19:30 Test transponder on deck next to 12 kHz pinger, fails sometimes; pinger possibly has bandwidth which interferes with 12.5-15 kHz Geodata systems. Change pinger to 2ms pulse length and 4 sec per pulse. (before 4ms and 1/sec)  
 21:00 Deploy for track 6 - intend to leave in till noon next day. Tracks 6,7,8,9 - all down Kohala slope

11/1/85

9:00 Maui beacons still having problems, one fully out. Call HIG to order 4 more to be sent to Maui airport. Install tomorrow. Plan to move Mini Ranger aft to serve as backup.  
 11:00 Tracks 6, 7, 8, & 9 run on mission 5, recovered. But battery failure stopped the data logger before track 6, all data lost.  
 12:00 Change pinger to 2 ms, frequency at 11.5 khz, 1 pulse per sec; new battery back, start track 10  
 15:15 Start track 11. Acoustic nav still not working - nothing below 800 m. Try to lower pinger frequency to 10 khz, bypass ship filters before Raytheon recorder so we can still use as a guide to the winch. Dave Harris working and reconfiguring the spare pinger. Working on data reduction from trisponder data (9826) to combine with BRS data - formats not as anticipated and taking a long time.  
 21:00 BRS pinger getting weak. Bring up BRS to check. Replace with new battery and lower frequency, 11 kHz pinger to improve transponder chances, bypass 12 kHz filters on ship so we can still hear pinger for bottom control. Put the pinger signal on the oscilloscope and watch both the strip chart recorders and the scope.  
 22:30 BRS back in water, track 13, mission 13. Acoustic Nav still doesn't work. Dave Harris looks at Geodata equipment and installs a notch filter for 11 khz at front end. Geodata has a wide band inlet filter that takes in our 12, 11.5, and even 11 kHz pinger signals.  
 24:00 Still having difficulty reading nav computer files, files not consistent.

11/2/85

- 02:45 Lose all Hana Trisponder and Mini Ranger stations. One Trisponder and one Mini Ranger down also at other Maui site. No navigation. Call Maui Tech - send to Hana. Proceed with GPS - good for about 5-6 hrs. - and manual plot. Complete runs 14, and do 15,16 on GPS. Try the notch filter in Geodata Systems, doesn't work. Plan: Run 15,16; wait for call from Hana, if not working by then, send Noda ashore at Hana.
- 04:45 End of run 14, Start 15 back on C3, area not as critical, proceed on GPS
- 10:00 Track 16 at bottom of slope. Maui still not up, GPS down. Recover BRS, recover Noda's current meters. Dave Harris modifies notch filter again - try on deck while recovering current meters (doesn't work).
- 11:00 Recover first current meter
- 11:45 Second current meter sighted, Maui, Hana station (one) comes up. Have navigation. Hana had lost power over night.
- 13:00 Prepare to launch BRS - Mission 17, Track 17, across top of area A
- 18:00 Start track 19, all trisponder ranges up
- 21:00 Complete track 20, move to Maui slope B.
- 22:30 Start track 21, Maui (600m) to Kohala slope, C1,B,C2 - 15 km

11/3/85

- 05:00 End Maui to Kohala slope run. Recycle BRS. Start track parallel top of Kohala slope. Saw very rough areas at top.
- 08:00 Turn and come down W of track 10, align for a cross tow along Kohala
- 09:00 Parallel to slope, mid slope - try to tie all previous runs together.
- 12:00 Come around for a run diagonally down slope, from West end toward bottom of run #3. Problems getting the surface navigation computer up and running plus concerns by the skipper over local tug traffic delays start of track.
- 16:00 Return to Maui, run 21 shows some significant roughness along whole route. Plan to do 24 hrs of runs in area, mostly to West side where SeaMark shows promise.
- 20:00 Winds 25 to 30 kts, 60 deg true, cannot hold course, doing loops, forced to reselect routes into the wind although less desirable.
- 20:42 Start cross Maui track #28

11/4/85

- 00:00 Start cross Maui track #29
- 03:38 Start cross Maui track #30, winds still strong
- 06:14 Winds down, try repeat of track #25 (now #31 & 32)
- 10:00 Winds increasing and some difficulty with course. Plan to move to Kohala, place Noda's current meters, run RBS w/o bottom pinger to get RBS relative position by bottom transponders (without pinger interference), try to catch up on Kohala processing and plan one or two more tows.

- 13:00 Start track 33 - 975 m out; without pinger. Some response from BRS transponder at first, no ranges however. Saw one range update to two bottom transponders. Raise cable 100m to 875, approx 150m off bottom - still no response. Cannot position lava flow as planned.
- 14:00 Move out over slope on track 34, and while going over Kohala slope, laved out more cable. 1200m out (exact winch reading), speed at 4.3-4.4 kts. RBS well aft. Get steady state for 5 minutes. At 14:20 (local time) at steady state and come to full stop. By 14:32 wire vertical. Later compare pressure to winch wire out.
- 14:35 Bring in at 300m increments, stop each time for signaling to the BRS transponder. No answer at 1200, 900, 600, or 300m. Haul on deck. Samwell wants to do a velocity probe (at their expense)
- 15:30 Commence recovery of transponders and deploying current meters.
- 18:30 Deploy last current meter and recover 3<sup>rd</sup> transponder. Have to be directly overhead to recover transponders. Two more to go.
- 19:00 Proceed to Kohala, Upolu Pt. and take data from there to Kohala slope. Noticed much more noise in echo sounder data, check out. Contact Tom Daniel at Kona if need more parts. Advise him later.
- 20:45 Echo sounder definitely has too much noise, must be repaired. Go to Kawaihae to get parts.
- 22:30 At Kawaihae, get parts for echo sounder. Dave Harris, in the meantime, has found loose component on ES elec board. They are very poorly made.
- 23:30 Check rebuilt echo sounder over side while leaving Kawaihae, Works fine, no noise. Proceed to Upolu Pt.

11/5/85

- 01:00 Make run from Upolu point toward area A. Straight down slope. Campbell didn't observe expected reef. According to Sea Mark data, crossed lava flow as approached Kohala drop off.
- 12:00 Last run for Kohala slope, run 40 to try to find between lava flows observed by both Sea Mark and RBS Recover RBS in winch steps documenting depths and wire out - clear up discrepancy between depths and wire out.
- 17:00 Recover last two transponders. One comes up without replying that it had released, just happened to see it.
- 18:30 Proceed to Maui slope. Tracks 41 through 45. Try to match cross tracks with Sea Mark data and pick a reasonable route. Lots of rough areas on Maui side.
- 23:00 Start track 42. Some problems with the Nav computer, keeps cutting out. Intermittent position data available. Keep RBS down till time to leave for home.

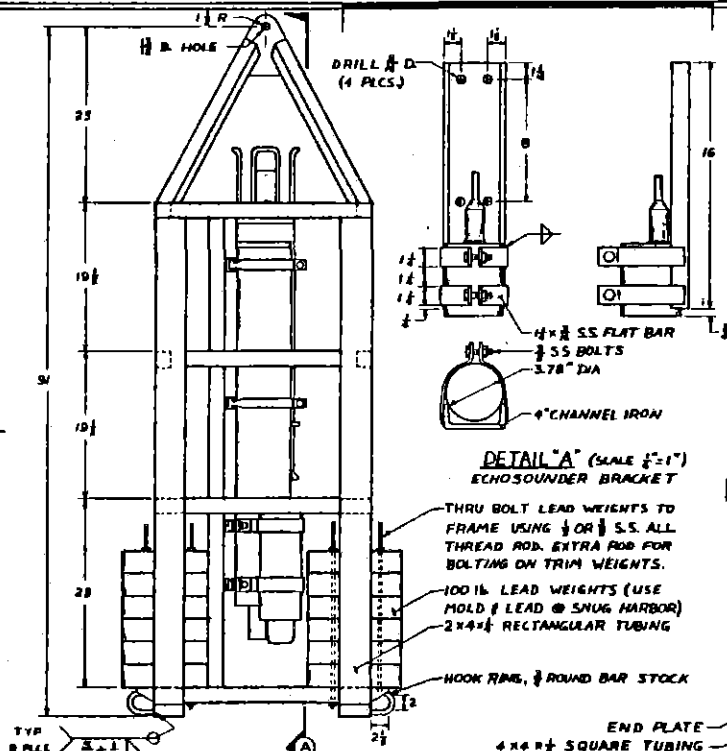
11/6/85

- 02:30 Start track 43
- 04:40 Start track 44, continuation of 43, blown off course slightly due to rain squall.

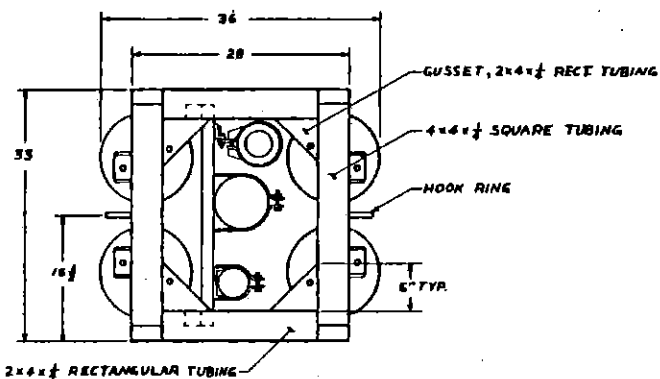
08:30 Start final track. To fit in before 10:30 departure,  
run course uphill. No problem, BRS operators fly up  
cliffs with ease. Haul up 100 m short of track end.  
10:31 RBS on deck, proceed to Snuq Harbor.  
22:00 Arrive Snuq Harbor (early - Moana Wave goes faster  
home). Cruise Pau.

Joe Van Ryzin  
Principal Investigator

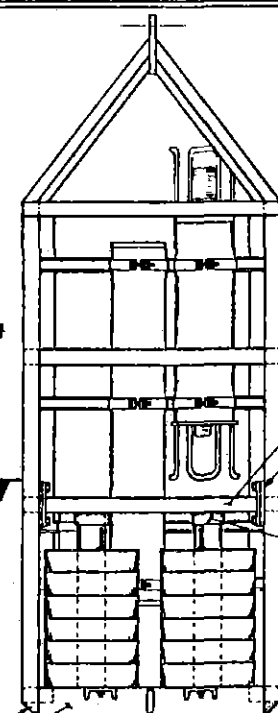
APPENDIX D  
BRS FRAME DESIGN



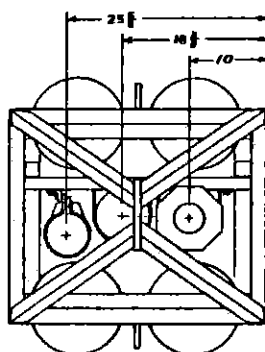
SIDE VIEW



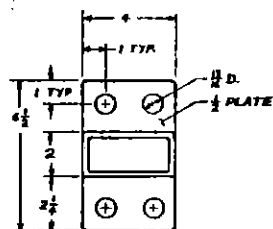
BOTTOM VIEW



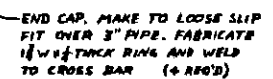
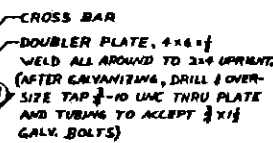
FRONT VIEW



TOP VIEW

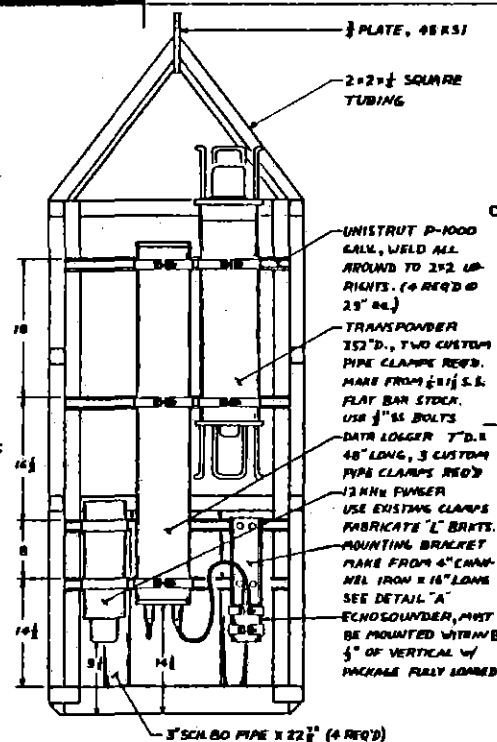


CROSS BAR ENDS  
(4 REQ'D)  
SCALE  $\frac{1}{2}$ "=1"

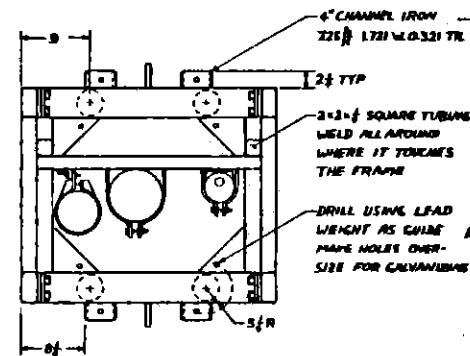


### NOTES

1. BUILD TWO FRAMES
2. BEVEL ALL ENDS TO BE WELDED
3. MAKE FULL PENETRATION WELDS
4. MAKE  $\frac{1}{8}$ " FILLET WELDS ALL AROUND
5. ROUND CORNERS & BREAK ALL SHARP EDGES
6. TORCH OR DRILL DRAIN HOLES IN TUBING FOR ZINC & WATER DRAINAGE
7. HOT DIP GALVANIZE FRAME, CROSS BARS, & ECHO SOUNDER MOUNTING BRACKET
8. USE  $\frac{1}{2}$ " BOLT TYPE ANCHOR SHACKLES TO ATTACH CABLE TO SWIVEL & SWIVEL TO B.R.L. FRAME (WELD NUTS TO BOLTS) & REQ'D
9. ALL DIMENSIONS IN INCHES



SECTION A (WEIGHTS NOT SHOWN)



SECTION B (WEIGHTS NOT SHOWN)

MAKAI OCEAN ENGINEERING, INC.

BOTTOM ROUGHNESS SAMPLER

BOX 1206, KAILUA, HAWAII, 96734

RECK LANEY 9-25-85

M-139

1 $\frac{1}{2}$ "=1'

APPENDIX E  
BEND RADIUS ANALYSIS

## ROUGHNESS ANALYSIS AND VERIFICATION

### INTRODUCTION

The life of a cable under tension is directly related to several important physical parameters. Cable span length and cable bend radius are two major parameters, arising from the choice of a cable route, which directly affect static and dynamic cable fatigue. Therefore, the number of critical spans and bend radii along a given route can be used as an indication of bottom roughness, and subsequent cable life. It is important therefore, to determine the number of occurrences of each, and which of these is the more limiting factor.

To accomplish this, a fast, reliable predictive method must be used to evaluate typical bottom profiles. This has been accomplished, after much research and development, through the use of a computer simulation of a laid cable. This analytic tool has been used to arrive at the conclusions in this document and is based on the equations suggested by Love (Reference 4) as the approximate solution for a stiffened catenary.

This appendix contains an explanation of the computer program which was developed, as well as the approximations used in Love's solution for bend radius and the consequences. In addition, a scale model was used to attempt to verify the accuracy of the computer analysis and Love's equations. Scaling procedures for the physical model, the results of modeling, and conclusions based on the comparison of these techniques are also presented.

### CONCLUSIONS

1. A quick, accurate method for predicting bend radius is not available to analyze a stiffened catenary, as opposed to predicting and more easily measuring cable sag. The computer technique is an approximate solution to a non-linear second order differential equation and thus is limited in certain situations. A numerical technique for solving the non-linear differential equations would be undoubtedly too slow, since each profile consists of hundreds of spans to be analyzed.

Additionally, a reliable, accurate method for measuring bend radius on a scale model of the cable is not available, as opposed to measurement of sag height. A scale model was built to verify predictions of the computer simulation. Although useful towards this end, the scale model had some limitations which barred precise determination of bend radii.

2. Although a precise measurement of bend radius could not be made on the scale model, a bend radius range could be identified. Based on the more accurately known values of tension, span length and



cable properties, a computer bend radius prediction could be compared to the model values. As a result, the computer program is seen to be conservative and can reliably be used to determine areas of critical and near-critical bend radii over the range of conditions to be encountered.

3. Based on Love's equation and a modeling of the cable, bend radius is determined to be relatively independent of tension over the range anticipated, although span length changes significantly with tension.

4. The height required to yield a critical bend radius decreases significantly as the asymmetry of the span increases, as determined by cable modeling. For an obstacle displaced 10% of the distance between touchdown points, the height yielding a critical bend radius is 60% of the height at the center.

5. From observations of the cable modeling, as the bottom slope increases, the slope-perpendicular height required to yield a critical bend radius diminishes slowly, reaching 80% of the 'level' height at a slope angle of approximately 30 degrees.

#### COMPUTER SIMULATION OF LAID CABLE

The computer program used in analyzing bottom roughness simulates a cable laid under tension along a given profile. This program is based on the equations given by Love (Reference 4), with added modifications.

The program proceeds by initially 'rolling' a ball, whose diameter is a function of bottom tension, along the bottom profile. This functional relation was derived by comparing various curves to a solution of Love's equation at various tensions, a circular arc being a fairly reliable and quick approximation to such solution. This method provides a first approximation of cable touchdown points, and is also used to determine neighboring spans which are used in approximating end conditions for the current spans.

Once the span conditions are determined, a modified form of Love's equation is then used to predict the true laid shape of the cable based on the span length, end conditions and bottom tension. The modifications are based on non-zero end conditions and an approximation for the effects of a sloping terrain. The analytically predicted cable shape is compared to the bottom terrain between the cable contact points to determine if there are any intermediate touchdown points. If so, a new analytical solution is found for the first span and so on until a clear span is found. Once a clear span is found, the bend radii at the ends are evaluated. If either the span length or bend radius is determined critical, the span location is flagged.

This computer program was compared against Love's equations for verification of simpler situations, and against the physical model for more difficult situations, to verify it's usefulness as a predictive tool in analyzing bottom roughness.

### LOVE'S EQUATIONS

Love solves the second order non-linear ordinary differential equation describing a catenary with stiffness by assuming the cable is nearly horizontal along the span. Thus his equations are valid only when there is minimal or no slope. In addition, the cable catenary must be symmetric, with the lowest point centered between the two supports. If the angle of the cable at the supports and in the center is 0 degrees, then the bend radius at the supports is given by:

$$r_{\text{bend}} = \frac{1}{(W/T_0) \left[ 1 - (\lambda L/2) \right]}$$

Where  $W$  = weight per unit length of cable  
 $L$  = length between supports

$\lambda = \sqrt{T_0/EI}$ , a function of cable stiffness

Since we are interested in finding situations yielding a critical bend radius, the above equation is solved for  $L$ , where  $r_{\text{bend}}$  is set equal to the critical bend radius ( $r_{\text{crit}}$ ).

$$L = (2/\lambda) \times \{ 1 + [ T_0 / (r_{\text{crit}} \times W) ] \}$$

Where  $\lambda > 2/L$  in our case.

Next we determine the height of the support as measured from the lowest point at the center of the cable as given by:

$$h = (W/T_0) \times [ (L^2/8) - (L/2\lambda) ]$$

Note that these equations assume uniform end conditions of slope = 0.0

The program which analyzed the bottom data was provided data for a situation which Love predicts would yield a 1.5 meter bend radius. The program's result was a 1.45 meter radius, which is desirable in that it is a little conservative. Thus the computer would flag some radii that are probably slightly greater than 1.5 meters. This is preferred because the program might exaggerate a bend radius slightly in a complex situation which is more difficult to analyze accurately.

## PHYSICAL MODEL

Love's equations are only valid for an obstacle on a horizontal bottom, and most of the proposed cable route is on slopes of varying degrees with obstacles of various heights. Thus, it is necessary to investigate the consequences of varying these parameters to insure that the computer analysis would still be valid under these conditions. The physical model was set up as a scaled version of the real cable and the heights at which the bend radius became critical were measured while varying the slope, symmetry, and length. Data which was not available from Love's equations was thus collected for comparison with the computer.

An additional reason for modelling the cable was to gather information about the trends associated with bend radii. Thus "rules of thumb" could be established to aid in the real-time cable route decisions which would be made during surveying. These trends are identified in the conclusion.

The physical model was scaled by determining the EI of available steel wire and subsequently scaling model parameters according to available materials. The cable was modeled with a stainless steel wire strung with lead fishing weights. Bend radius and span length were scaled to reasonable values by proper selection of wire diameter and lead weight size, although selection was limited to certain stock sizes. The resultant cable scaling factors are: 1/26 in length, and 1/976 in force.

## MODEL RESULTS

The physical model was first compared with Love's equations to verify that it was working accurately and to investigate the extent of errors such as friction. For the tensions encountered friction was insignificant and other sources of error were identified and controlled satisfactorily. The measured amount of sag,  $h$ , agrees with Love's predictions extremely well over the range of parameters used to take the data.

Unfortunately, the comparison with Love's equation for bend radius was less conclusive. Two Bend Radius Indicators (BRI 1 and BRI 2) were made which would indicate when a critical bend radius had been reached by illuminating LED's. BRI 1 measured the radius over a minimum arc length of approximately 0.25 in., and therefore had poor repeatability and was difficult to use. BRI 1 was calibrated against Love's Equation and was only used for a short time to take data on trends. BRI 2 (shown in figure E.1) was built as an attempt to overcome these limitations and could indicate a critical radius over an arc length of only 0.04 in. Unfortunately, in decreasing the detection area, other difficulties were encountered. These were assumed to be due to non-uniformities in materials and extreme pressures (estimated at 20,000 psi under some

conditions) which deform the contact plates and also flatten the radius indicated. To avoid difficulties BRI 2 was calibrated by noting that six LED's were on at a height predicted by Love as yielding a critical bend radius.

When Love solves the differential equation describing a catenary with stiffness he assumes that the catenary is nearly flat and thus simplifies the original equation so that it has an analytic solution. While investigating the problems with BRI 2, it was decided to investigate to what degree these assumptions affected the predicted conditions for a critical bend radius. As a quick qualitative test, a solution to Love's equation was inserted back into the original differential equation and it was discovered that this solution is good over 95% of the span. Unfortunately, where it seems to be in greatest error is precisely where we are interested in knowing the bend radius (i.e., at the end points). Without determining a numerical solution to the original equation it is difficult to estimate the severity of this error and it's effect on bend radius at the endpoints. This error does not affect the the predictions of cable sag in the center to any noticeable degree, as verified using the more easily measured model sag.

Figure E.2 is a graph showing how Love's equations predict that the height required to produce a critical bend radius and the span vary with cable tension. The desired range of tensions to model were from 500 to 5,000 kg and the height varies very little over this range. However, over the same range of tension, the span length changes on the order of 300%. This implies that for a given obstacle height the bend radius will remain almost constant while the span length will change considerably, as tension varies.

No attempt was made to generate the entire graph in figure E.2 experimentally because of the small changes in height involved and increasing frictional effects at lower tensions. However, agreement was observed between these results and the model. When tensions were changed by about 10%, no measurable change in height was noticed, although L decreased proportionally.

Figure E.3 shows the model setup used to take the data for the graph in figure E.4. L is the distance between touchdown points and d is measured from the left touchdown point to the obstacle. The bend radius was determined, in this instance, by comparison to a plexiglass template scribed with various radii. The wire was first lifted until the radius observed was approximately 1.65 meters scale, and the height was recorded as h MIN. The obstacle height was raised further until the bend radius was approximately 1.55 meters scale, at which the maximum height, h MAX, was recorded. In all cases the wire lifted off from the touchdown points (i.e., L increased) before h MAX was achieved, indicating that the bend radius could not be decreased unless tension were decreased or length increased. At a d/L of 50%, the difference between h MIN and h MAX was about 1.3 meters scale, with the average value very close to Love's prediction.

As seen in figure E.4,  $h$  decreases significantly as the obstacle moves toward either touchdown point (previous results show the graph is symmetric). It was later determined that the liftoff envelope is related to the position of the outermost pulleys, but forcing the wire to touch at the touchdown points would yield an undesirable non-zero angle there.

In figure E.5 the outermost pulleys and touchdown points have all been arranged on a 12 degree slope. BRI 2 was used for this graph with six LED's representing a 1.5 meter radius. Note that the peak height has shifted from 50%  $d/L$  in figure E.4 to about 40% here. Additionally, the height of the peak has decreased from 3.3 meters in figure E.4 to about 2.8 meters here.

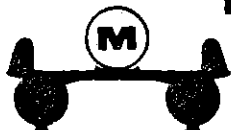
The liftoff envelope here has shifted significantly from figure E.4 and it seems that for even greater angles it would prevent any data to be taken in the most interesting area near  $d/L = 50\%$ . Additionally, smaller angles would not add any significant insight to the trends, so no further data was taken.

The setup used to take the data for figure E.6 was unique to this graph. Instead of using inner pulleys for the touchdown points we substituted a piece of angle iron to simulate a slope on the ocean bottom. Guidelines for use during cable deployment were desired for the case where the slope and obstacle height were known but the touchdown points unknown.

The graph in figure E.6 shows that  $h$  decreases minimally as the slope increases. Figure E.5 shows a decrease in height from figure E.4 and thus supports the trend here. However, the actual measurements cannot be compared because no data exists for  $d/L = 50\%$  in figure E.5 and  $d/L$  remained constant at  $50\% \pm 1\%$  for this graph.

#### COMPARISON OF PHYSICAL MODEL AND COMPUTER PROGRAM

Several cases were modeled from the bottom roughness data for which the computer program indicated critical bend radii. Situations were chosen having bend radii very near the critical limit since we could only indicate and not measure bend radii with BRI 2. In all of the cases the model agreed very well with the computer predictions.



**MAKAI OCEAN ENGINEERING, INC.**

P.O. BOX 1206, KAILUA, OAHU, HAWAII 96734

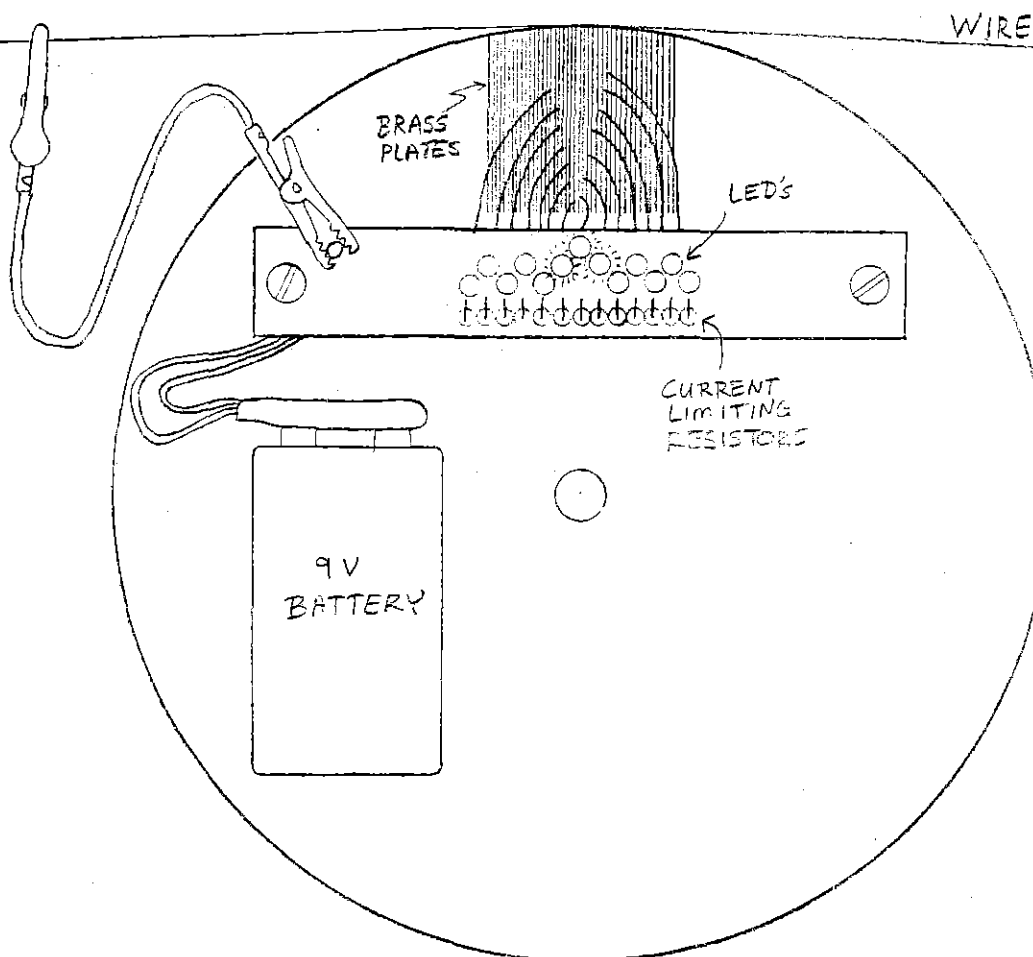
(808) 259-5940

DATE: 5/1/86

BY: AY

PROJECT: ROUGHNESS

## BEND RADIUS INDICATOR 2



### OPERATION:

WHEN WIRE CONTACTS  
BRASS PLATE, CORRESPONDING  
LED IS ILLUMINATED.

Figure E1

# OBSTACLE HEIGHT AND SPAN LENGTH vs. TENSION

ANALYSIS USING LOVE'S EQUATIONS

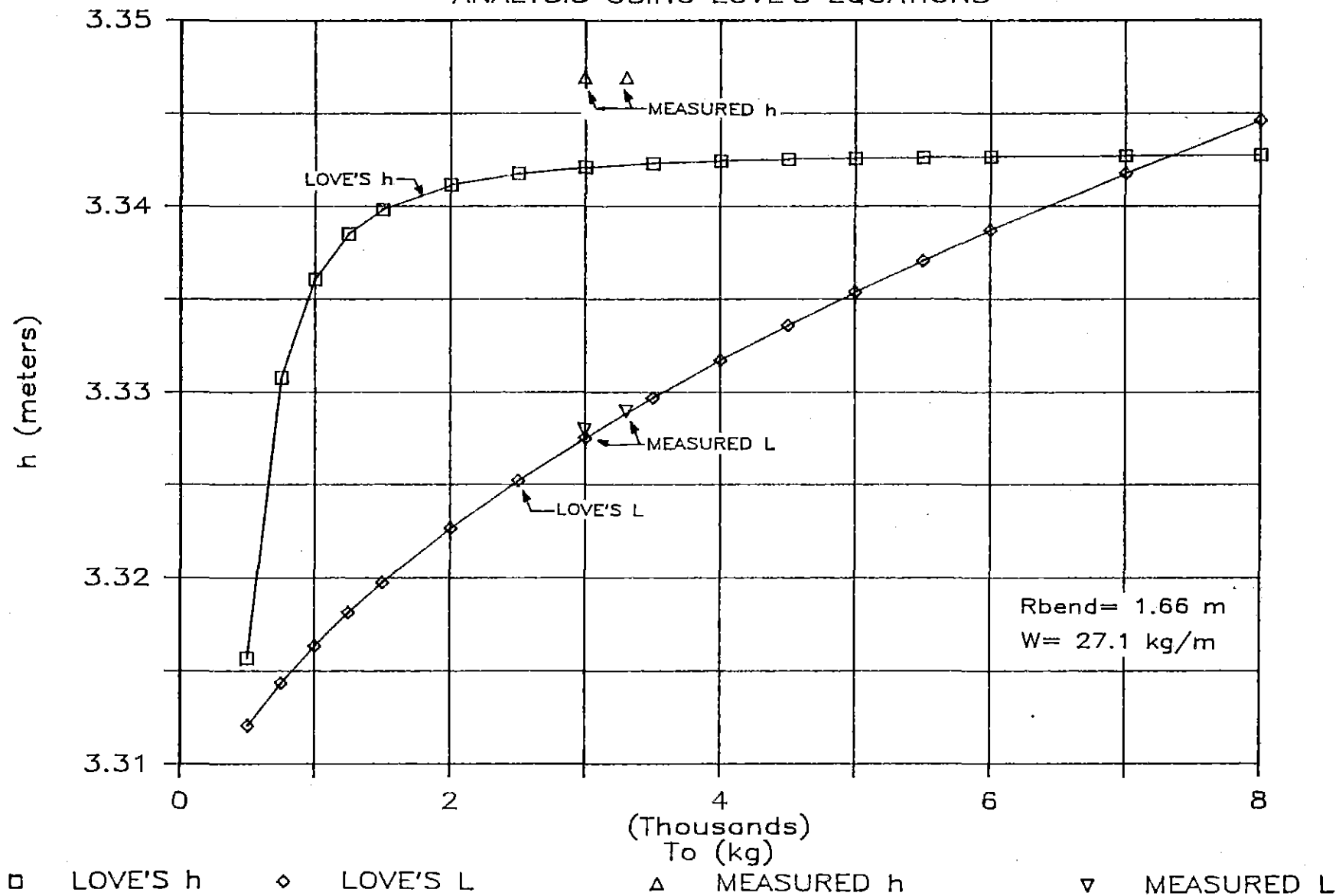
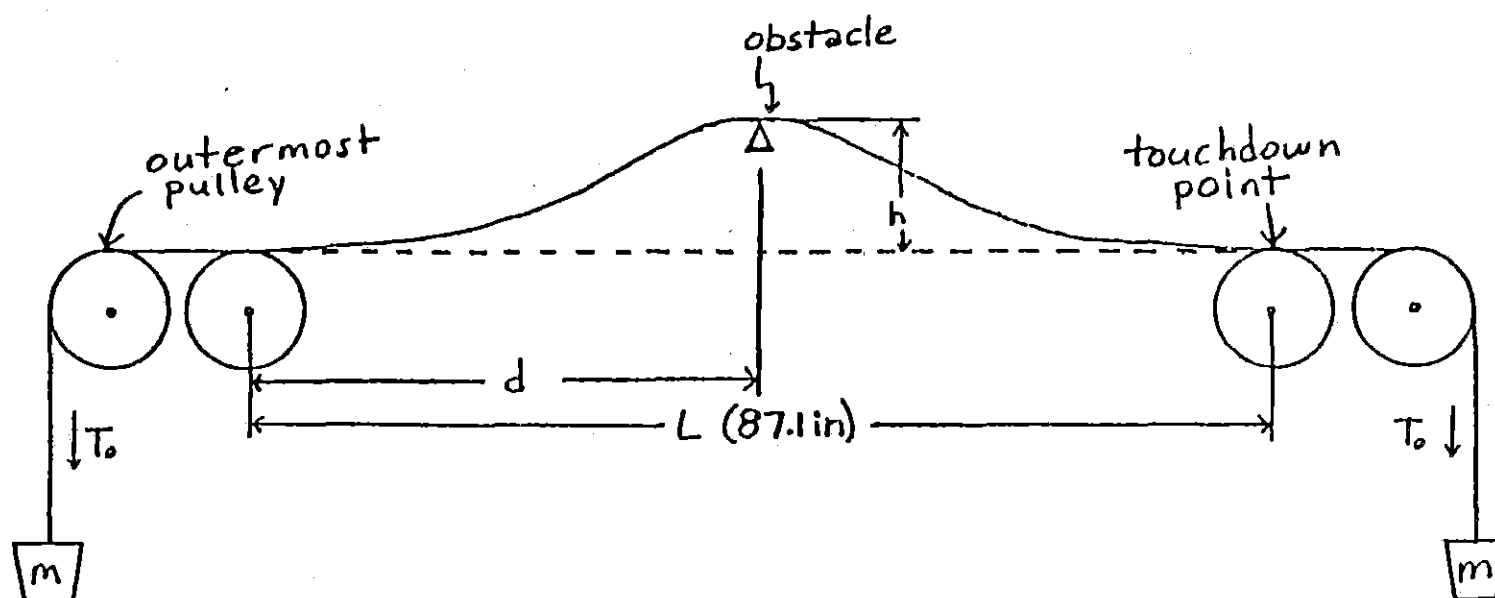


FIGURE E.3



PHYSICAL MODEL ARRANGEMENT



# OBSTACLE HEIGHT vs. SYMMETRY

NO SLOPE, TOUCHDOWN POINTS FIXED

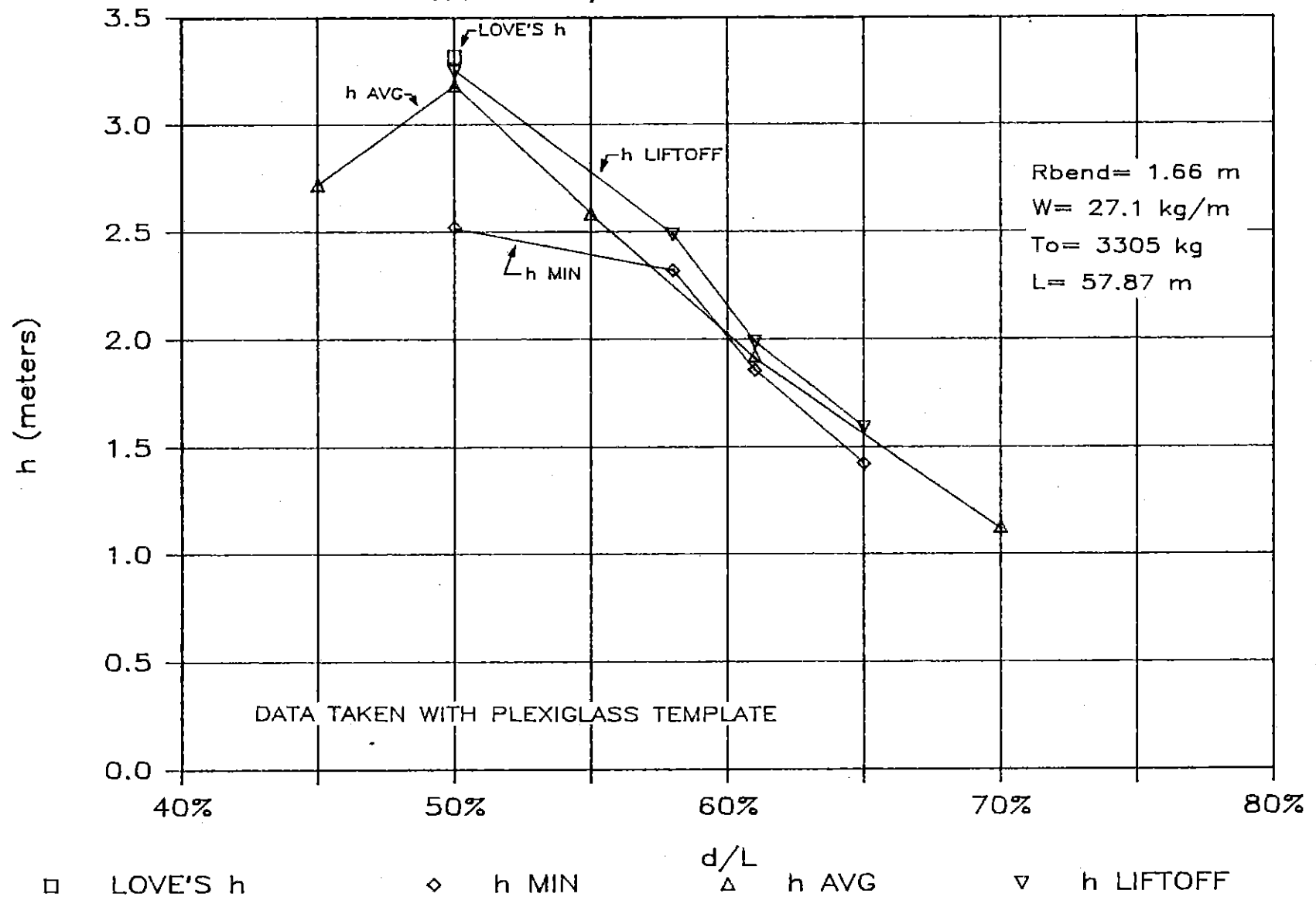


Figure E4

# OBSTACLE HEIGHT vs. SYMMETRY

12° SLOPE, TOUCHDOWN POINTS FIXED

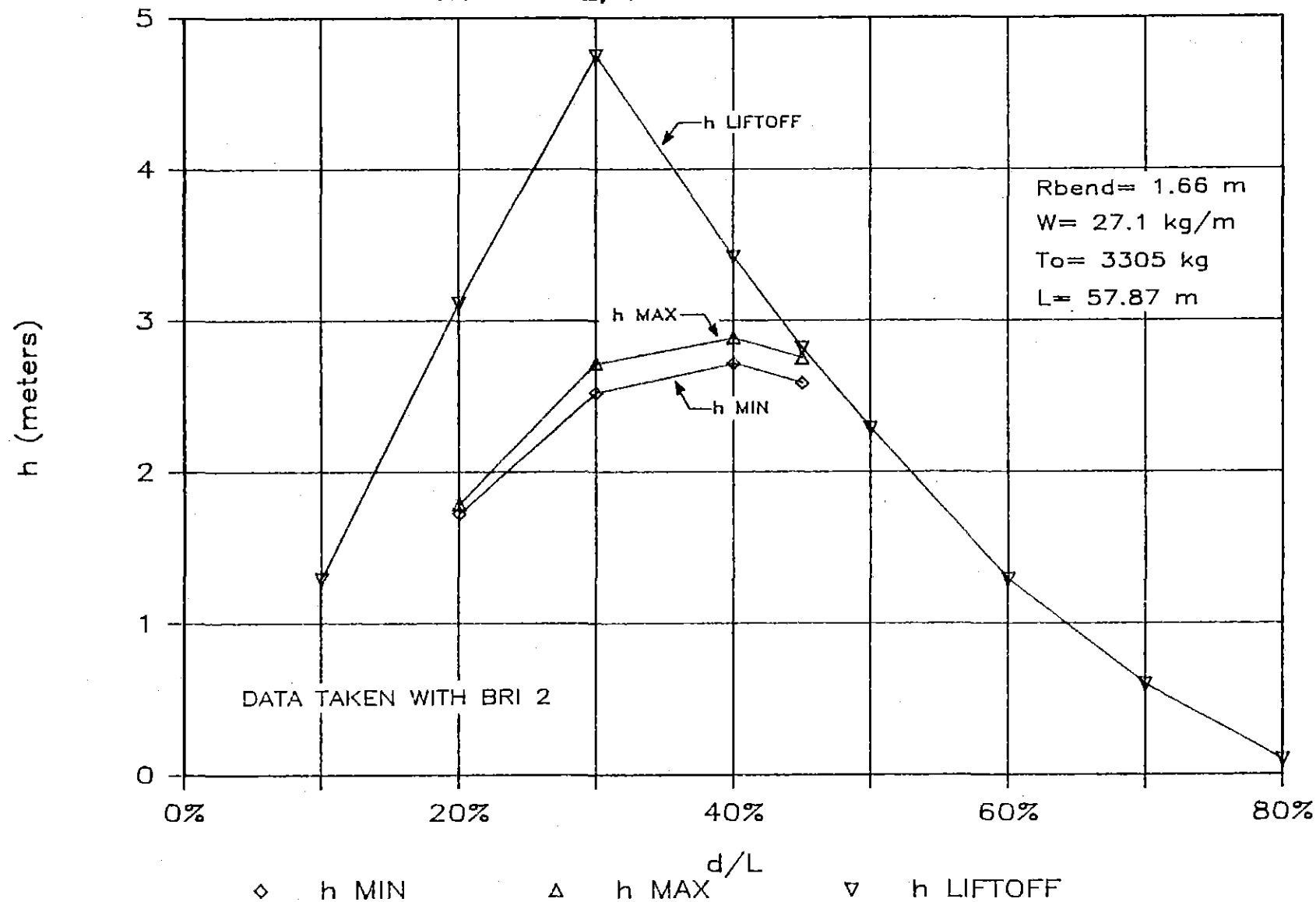


Figure E5

# OBSTACLE HEIGHT vs. SLOPE

TOUCHDOWN POINTS ALLOWED TO VARY

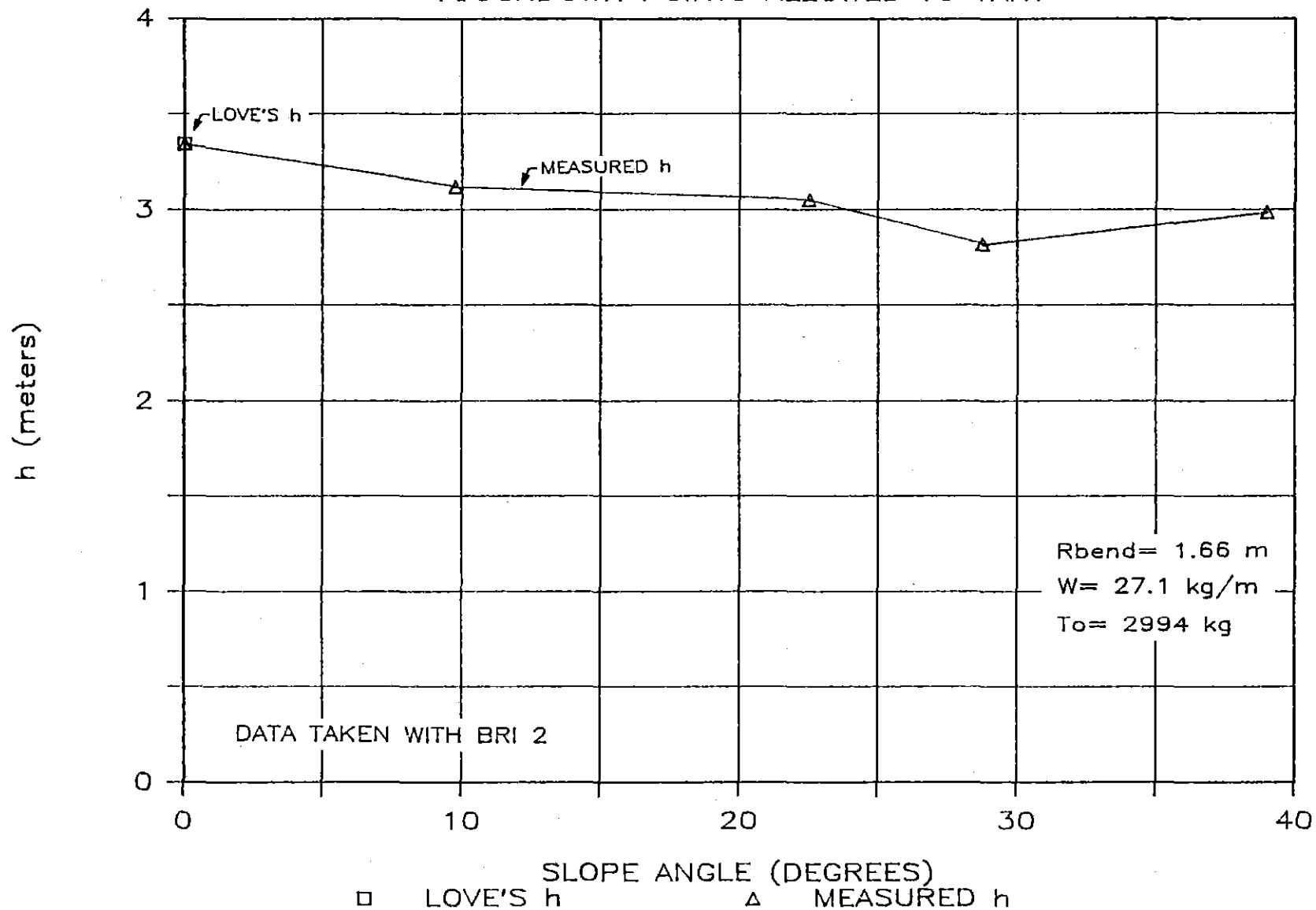


Figure E6

APPENDIX F  
ACOUSTIC WAVE REFRACTION

# EDWARD K. NODA & ASSOCIATES

OCEANOGRAPHIC CONSULTANTS

## MEMORANDUM

DATE: September 24, 1985

TO: Joe Van Ryzin, Makai Ocean Engineering, Inc.  
Frank McHale, Hawaiian Dredging and Construction Company

FROM: Ed Noda

SUBJECT: Bottom Roughness Survey, HDWCP  
Acoustic Long Base Navigation System  
Bottom Transponder Layout and Mooring Design

In my conversation with Fred Spiess, Scripps Institution of Oceanography, he indicated that the mooring design and deployment layout of the bottom transponders for the acoustic long base navigation system required consideration of the refraction effects associated with acoustic ray propagation between a near-bottom transponder on a towed vehicle and the bottom mounted transponders. For the deep water depths that the Scripps' Deep Tow system operates in, the water temperature is essentially isothermal with the sound velocity increasing only with water pressure or depth. This then bends the acoustic rays upwards by refraction and thus "even if the seafloor is a horizontal plane, no direct path may exist between near-bottom source-receiver pairs." Figure 1 reproduced from the "Seafloor Referenced Positioning: Need and Opportunities", National Academy Press, 1983 describes this problem, where a source located 100 meters off the bottom can only be heard by a receiver located above the limiting ray path which is just tangent to the horizontal ocean bottom. Thus within the shadow zone described in Figure 1, the receiver will not be able to hear the source transmission.

For a vehicle being towed very near the bottom, Figure 1 indicates that the maximum range between the tow vehicle acoustic receiver and a bottom mounted transponder located 100 m off the bottom is about 4.2 km assuming a horizontal ocean bottom and deep water depths. While Figure 1 indicates the physics of the problem, for the Bottom Roughness Survey actual refraction calculations are required for the Alenuihaha Channel and its non-horizontal bottom topography. This memorandum describes a preliminary evaluation of sound path ray refraction in order to provide information for the mooring design height of the transponders off the bottom and their plan layout configuration.

Figure 2 schematically describes the ray path or orthogonal coordinate system being propagated over a sloping bottom with slope angle  $\beta$ . The geometric optics ray equations describing the ray wave are assumed to apply, given by the following:

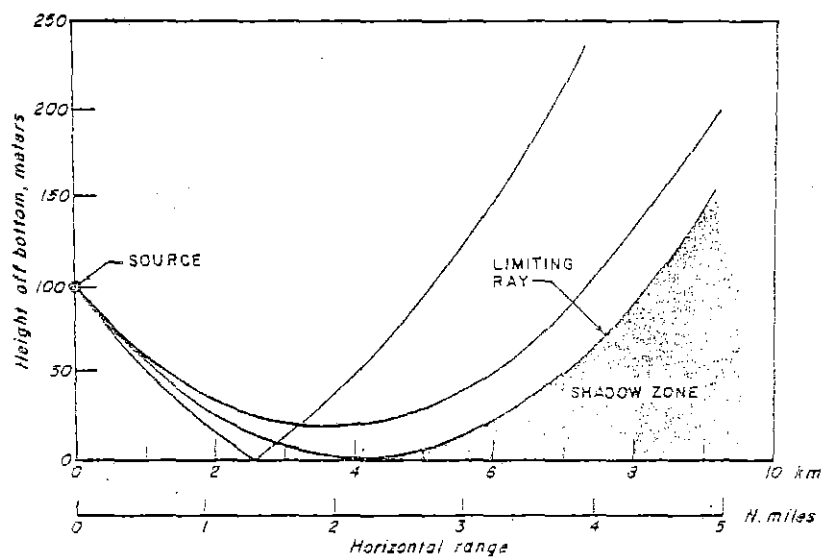


FIGURE 1 Effects of upward refraction for a near-bottom sound source in isothermal water (from Spiess, 1966).

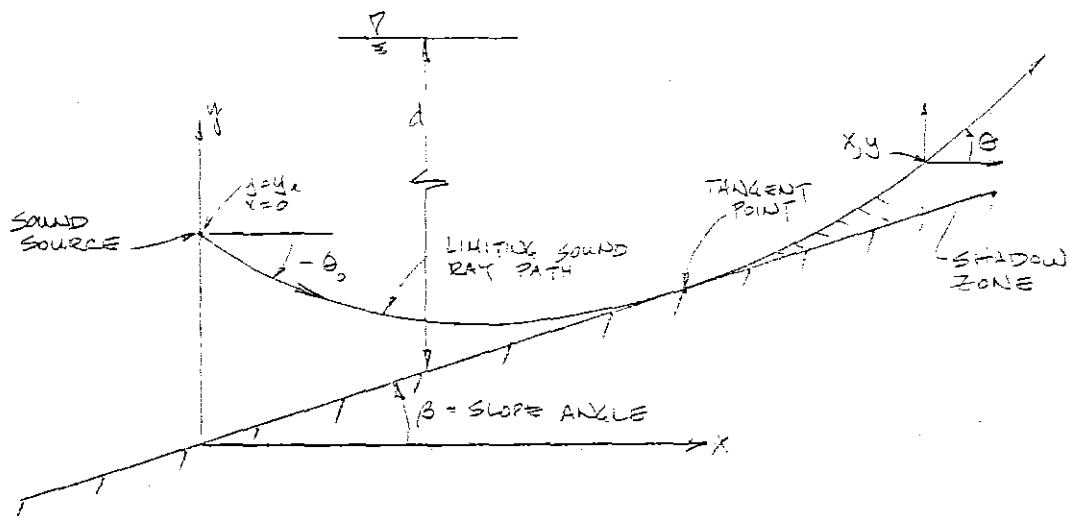


FIGURE 2 SOUND RAY COORDINATE SYSTEM

$$\begin{array}{ll}
\frac{dx}{ds} = \cos \theta & 1 \\
\frac{dy}{ds} = \sin \theta & 2 \\
\frac{d\theta}{ds} = \frac{1}{C} \left( \sin \theta \frac{dC}{dx} - \cos \theta \frac{dC}{dy} \right) & 3
\end{array}$$

where C is the speed of sound which is a function of salinity, temperature and pressure. From Wilson (1960)

$$C = 1449.22 + \Delta C_T + \Delta C_P + \Delta C_S + \Delta C_{STP}$$

where

$$\Delta C_T = 4.6233T - 5.4585 \times 10^{-2}T^2 + 2.822 \times 10^{-4}T^3 - 5.07 \times 10^{-7}T^4$$

$$\Delta C_P = 1.60518 \times 10^{-1}P + 1.0279 \times 10^{-5}P^2 + 3.451 \times 10^{-9}P^3 - 3.503 \times 10^{-12}P^4$$

$$\Delta C_S = 1.391(S-35) - 7.8 \times 10^{-2}(S-35)^2$$

$$\begin{aligned}
\Delta C_{STP} = & (S-35)(-1.197 \times 10^{-2}T + 2.61 \times 10^{-4}P - 1.96 \times 10^{-7}P^2 - 2.09 \times 10^{-4}PT) \\
& + P(-2.796 \times 10^{-4}T + 1.3302 \times 10^{-5}T^2 - 6.644 \times 10^{-8}T^3) \\
& + P^2(-2.391 \times 10^{-7}T + 9.286 \times 10^{-10}T^2) - 1.745 \times 10^{-10}PST
\end{aligned}$$

and where

P = absolute pressure (kg/cm<sup>2</sup>)

T = temperature (°C)

S = salinity (o/oo)

C = sound velocity (m/sec)

Since the spatial gradients of salinity and temperature are small relative to the vertical changes, it is assumed that salinity and temperature are only functions of y. Consequently, in Equation 3 the dC/dx term is zero.

The three 1st order differential equations describing the ray characteristics, Equations 1-3, were solved using an integration operator. For this analysis a Richardson Extrapolation integration scheme was utilized. It is interesting to note that numerical tests comparing a Richardson Extrapolation method versus a 4th order Runge-Kutta integration method showed that for the above 3 equations, for the same computational effort, the Richardson Extrapolation produced a 10 factor increase in accuracy.

While ocean water salinity and temperature vary as a function of the seasons of the year, the dominant variation is in the upper water column between the surface to about 200 meters. At deeper depths the salinity and temperature show much smaller seasonal changes. Thus for the refraction analysis, a typical deep depth temperature and salinity profile for Hawaiian waters was used (Knauss, 1978). The attached table provides this data.

While the program is designed for any arbitrary bottom slope angle  $\theta$ , initial tests were for a horizontal bottom,  $\theta=0^\circ$ . Since it

**Table 1.4** Values of temperature, salinity, density, dynamic height, and stability for a hydrographic station in the North Pacific, 17°04'N, 162°24'W, depth 5726 m

Z	S	T	$\theta$	$\sigma$	$\sigma_t$	$\sigma_\theta$	$\Delta_{\sigma}$	$\delta$	$\Sigma \Delta D$	$E(10^{-4} \text{m}^{-1})^*$
0	35.003	27.20	27.20	22.68	22.68	22.68	518	518	4.13	—
10	35.000	27.19	27.19	22.73	22.68	22.68	518	519	4.08	—
20	34.997	27.18	27.18	22.77	22.68	22.68	518	519	4.03	—
30	34.995	27.18	27.17	22.81	22.68	22.68	518	519	3.97	—
50	34.992	27.06	27.04	22.93	22.72	22.72	515	517	3.87	2500
75	35.028	25.58	25.56	23.53	23.21	23.21	468	471	3.75	2100
100	35.079	23.83	23.81	24.21	23.77	23.78	414	418	3.64	1800
125	35.096	22.47	22.44	24.72	24.18	24.18	375	380	3.54	1600
150	35.071	21.14	21.11	25.19	24.53	24.54	342	347	3.45	1400
200	34.836	18.10	18.06	26.02	25.14	25.15	283	290	3.29	1200
250	34.438	14.22	14.18	26.85	25.73	25.73	228	235	3.15	1100
300	34.186	10.85	10.81	27.54	26.19	26.20	184	190	3.05	730
400	34.181	8.07	8.02	28.47	26.64	26.65	141	148	2.88	380
500	34.271	6.54	6.49	29.22	26.93	26.93	114	121	2.75	230
600	34.376	5.84	5.79	29.87	27.10	27.11	97	105	2.63	140
700	34.454	5.47	5.41	30.43	27.21	27.22	87	96	2.53	110
800	34.490	4.96	4.90	30.99	27.30	27.30	79	88	2.44	85
1000	34.524	4.14	4.06	32.04	27.42	27.42	67	77	2.28	63
1200	34.552	3.47	3.38	33.05	27.51	27.51	59	68	2.13	48
1500	34.592	2.76	2.65	34.54	27.60	27.61	50	59	1.94	35
2000	34.638	2.07	1.93	36.94	27.70	27.71	41	50	1.67	20
2500	34.663	1.76	1.58	39.25	27.74	27.76	36	46	1.44	12
3000	34.674	1.61	1.38	41.51	27.76	27.78	35	45	1.21	8
3500	34.682	1.52	1.25	43.73	27.78	27.79	33	44	0.99	5
4000	34.688	1.48	1.15	45.91	27.78	27.81	33	45	0.77	3
4500	34.696	1.45	1.06	48.08	27.79	27.82	32	45	0.54	2
5000	34.700	1.45	1.00	50.21	27.80	27.83	31	46	0.32	2
5500	34.700	1.48	0.97	52.31	27.79	27.83	32	48	0.08	—



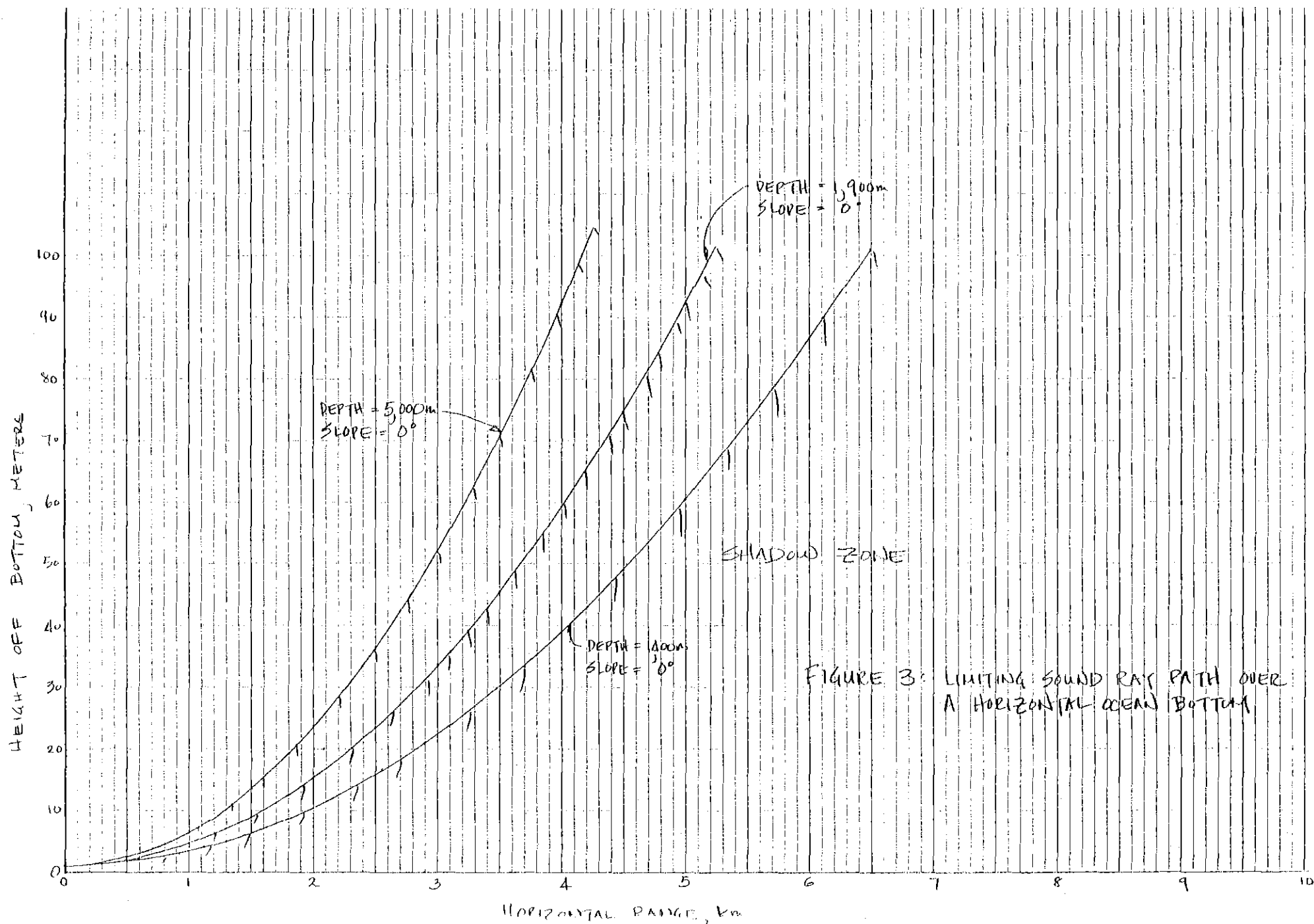
was assumed that the limiting ray path shown in Figure 1 was generated for deep water, a depth of 5,000 meters was given, and calculations for the limiting ray were performed. Figure 3 provides the results of this analysis. For efficiency, since the ray path on a horizontal bottom is symmetrical about the tangent point with the bottom, the computation was initiated at the tangent point (actually 1 meter above the bottom) and only one side of the ray path was calculated. From Figure 3, for a water depth of 5,000 meters, the limiting ray distance from the tangent point to a source/receiver point located 100 meters off the bottom is about 4,200 meters. Scaling Figure 1 shows good correlation. This similar computation was also performed for water depths of 1,900 and 1,400 meters as shown in Figure 3. Notice that as the water depth decreases, the limiting distance between the source and receiver increases for similar transponder configurations.

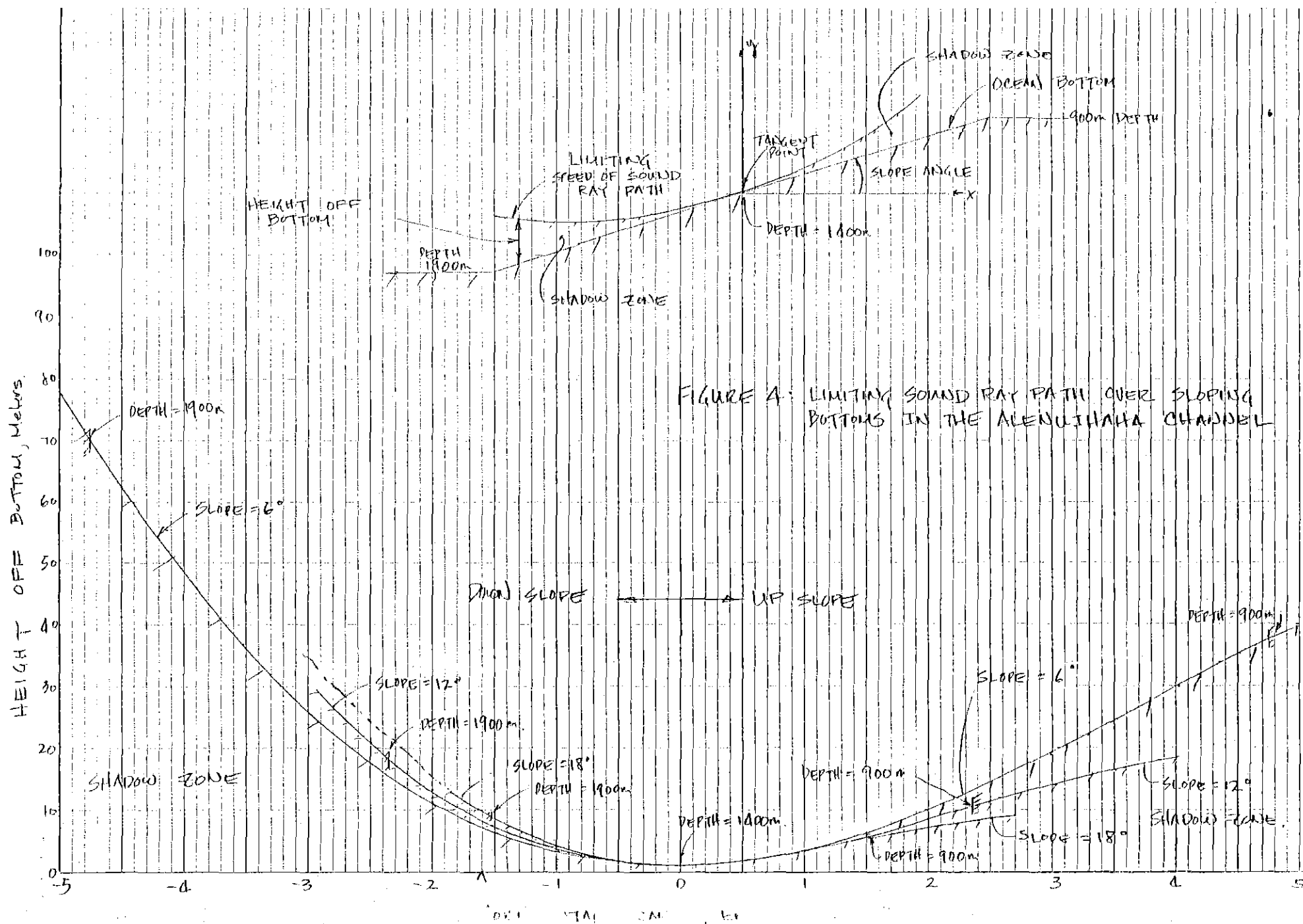
While the bottom slope in the Alenuihaha Channel is typically not horizontal, Figure 3 provides information should the towed vehicle receiver and the bottom transponder be located at the same water depth. The more typical situation would involve a sloping bottom with the source or receiver being either up or down slope. The mean Kohala slope between water depths of 950 and 1,850 meters is about  $18^\circ$ . Since the relative slope between a bottom mounted transponder location and a near-bottom moving vehicle can vary between 0 to  $\pm 18^\circ$ , computational runs were performed for 6, 12 and  $18^\circ$ . For simplicity and to avoid lengthy iterations, a tangent point on the slope was selected to be half way along the slope at a depth of 1,400 meters. Again, a distance of 1 meter off the bottom was used at this tangent point. Since the limiting ray is not symmetrical, the solutions for the limiting ray propagation were performed for both the up slope and down slope directions. Figure 4 provides the results of this analysis.

Figure 4 provides the height off the bottom of the limiting tangent ray as a function of the horizontal distance up and down slope for different bottom slopes. In Figure 4 the locations along the slope when water depths of 1,900 and 900 meters are reached, have been noted. Since the program assumes that the bottom slope continues infinitely, the height off the bottom data beyond these depths is not representative of the actual situation on the Kohala slope.

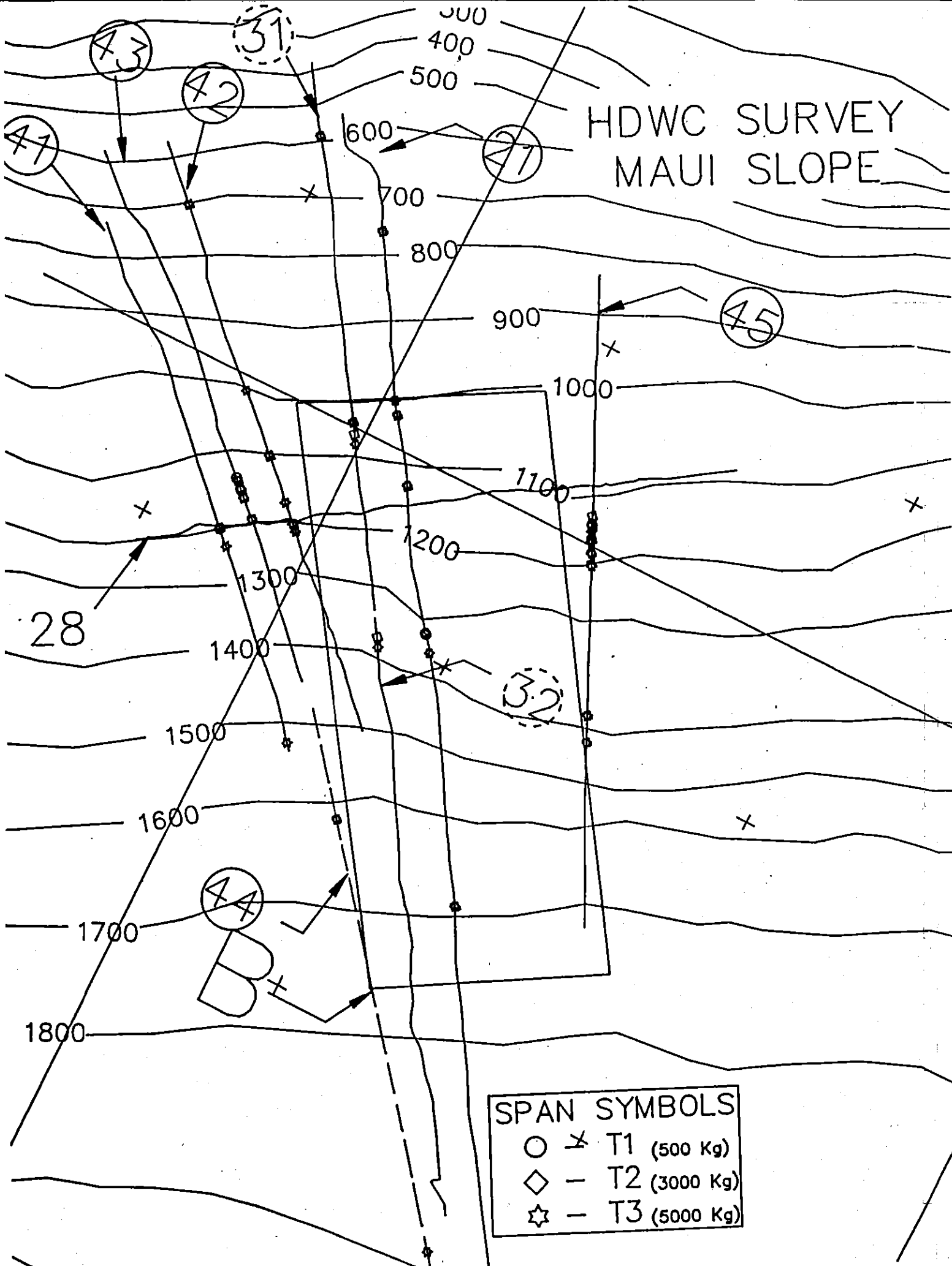
It is presently envisioned that the vehicle will be operated typically about  $30 \pm 10$  meters off the bottom. Nevertheless, there may be times when the vehicle is much closer to the bottom and thus a source/receiver location for the master transponder on the vehicle should probably be between 0-10 meters.

The following information is being provided for use in laying out the plan view configuration of the bottom transponder network which is being performed by Makai Ocean Engineering and Sci-Tech/Geodata.





# HDWC SURVEY MAUI SLOPE



SPAN SYMBOLS	
○	T1 (800 Kg)
◇	T2 (3000 Kg)
☆	T3 (8000 Kg)

